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WITH PLATE I.

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AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

ART. VI.—*On Geometric Sequences of the Coronas of Cloudy Condensation, and on the Contrast of Axial and Coronal Colors;** by C. BARUS.

Introductory.

1. THE object of the following paper is, in the first place, to map out the sequence of coronas in case of water vapor, in terms of the numbers of particles producing them, relatively. The extreme diversity of coronal display seen in moist nucleated air lends itself well to a geometric method of classification when the colors are produced by successive exhaustions. The classification is thus primarily suggested by experiment.

In the second place, I shall make certain theoretic deductions from the time losses of nuclei observed, which clear up some moot points left in abeyance in my earlier experiments on the same subject.

I purpose in the third place to contrast the color of the central patch of the coronas with the axial colors seen in the steam jet, or under like circumstances with even greater saturation, in the adiabatically exhausted drum. The coronas must in large measure be diffraction phenomena; the axial colors cannot be so explained, but are evoked by some unknown kind of absorption. The contrast is sharply brought out by the experiments.

Finally I shall make an estimate of the absolute dimensions of the water particles in action and of their number and indicate a method which I am pursuing in a quest for definite absolute results.

2. *Apparatus.*—In my first experiments tubular apparatus was used in great variety; but in these instances the colors are

*The researches outlined in the present paper are encouraged by a grant from the Smithsonian Institution. Here I can only acknowledge my indebtedness to Secretary Langley, for his patience and confidence.

too fleeting, and if obtained artificially with nuclei, the colors are apt to be too dull for good discrimination. The charge of nuclei is removed too rapidly by the condensation; and if the tube is horizontal, two longitudinal vortices are seen immediately after exhaustion, the air rising on the outside and descending into the center. Finally there is no guaranty that the charge of nuclei added is uniformly distributed. Tubes have one advantage, however, of affording a demonstration of the occurrence of rigorously axial colors.

For studying coronal effects spherical receivers, 30 cm. or more in diameter, as used by Coulier and Kiessling, are preferable. With divergent sunlight the display is gorgeous, the colors glowing metallically. The mantel of a Welsbach burner seen through a small hole in a screen is better for experimental purposes. The axial colors are not very vivid from the small thickness of medium traversed; but the diffraction colors are bright, particularly on blotting out the central beam with a small black circular screen. Vortices are no longer violent. They serve a useful purpose in keeping the contents of the receiver homogeneous.

As a whole, the defraction pattern is a contraction inward of dark rings as the particles, during the course of exhaustion of the nucleated moist air, grow larger. With white light these occurrences are, however, by no means a succession of ordinary coronas. The initial and particularly brilliant coronas corresponding to finer particles have colored* central fields, and it is only after many successive exhaustions that the normal, truly white centered corona is reached.

The information first to be sought is some classification of the sequence of coronal colors and of the axial colors seen in these experiments. These contrasting phenomena are radically different. If the former are in large measure diffractions, the latter are absorptions. The axial color is always nearly complimentary to the central field of the corona. As the particles grow in size, both central color phenomena pass through Newton's series at a definite phase difference apart, but the axial colors grow faint and vanish long before the diffraction colors.

Coronas.

3. *Loss of nuclei by exhaustion.*—Omitting preliminary results, it will now be necessary to investigate data of a quantitative character, serving to distribute the coronas in a scale of decreasing numbers of nuclei. It will not be feasible to arrive at the latter datum at once; for the number of nuclei must be

* The narrow white sheen around the axis mentioned in the tables below is probably irregularly diffused light.

supposed to vary both with the drain due to the successive equal exhaustions and, in the second place, to causes independent of manual interference, such as are involved in the motion of the nucleus (absorption by the walls, subsidence when loaded, etc.) and its possible decay. It is my present purpose to determine the most potent cause of dissipation.

Accordingly, in the following experiments the effect of exhaustion is first fully treated. The large globe was partially exhausted and refilled about twenty times in succession, the pressures falling off from normal to about 18^{cm} below. The air which replaced that removed was carefully filtered and the influx slow enough through pressed cotton to insure efficiency.

TABLE I.—Color sequences of successive Coronas. Axial colors. Residual nuclei. Each exhaustion from 76^{cm} to 58^{cm}.

$N = 10^{n(1+b)\log y}$; $y = \cdot 819$; $t = 96$ sec.; $b = \cdot 1$; $N_0 = 1 \cdot 000$.

Exh. No.	Coronas.	Axial color.	$N_1 \times 10^3$	$N_2 \times 10^3$	$N \times 10^3$	$\sqrt[3]{1/N}$
1	Yl fog, red rimmed	Bl	731	800	793	1·08
2	Do.	Bl	535	640	629	
3	Gray, rd, { gr / yl	Bl	391	512	499	
4	Viol, rd, yl-gr	--	286	409	396	
5	Bl-gr, rd	Yl	209	327	313	1·47
6	Gr, prp	Or	153	262	249	
7	Gr-yl, rd, gr, rd	—	112	210	197	
8	Yl, br, gr, rd	Violet	82	168	156	
9	Yl, rd, gr, prp		60	134	124	
10	Wh, prp, yl-gr, rd, gr		44	107	98	2·17
11	Wh, bl-gr, br-rd, gr, rd		32	86	78	
12	Apple gr, rd, buff, rd		23	60	62	
13	Gr-yl, br-rd, gr, rd		17	55	49	
14	Wh, br, gr, rd		12	44	39	
15	Wh, cr, gr, rd, gr		9	35	31	3·19
16	Wh, br, gr-yl { rd / gr		7	28	24	
17	Wh, bl-gr, rd, gr		5	22	19	
18	Yl-gr, bl, rd, gr		4	18	15	
19	Wh, br, gr, rd		3	14	12	
20	Do. Small ordinary coronas		2	11	10	4·69

With each exhaustion a corresponding amount of nuclei are removed with the air. Thus after n exhaustions from pressures p_0 to p, the residue of nuclei should be $(p/p_0)^n$ under isothermal, and $(p/p_0)^{n/\gamma}$ under adiabatic conditions (γ being the ratio of the specific heats), admitting what is by no means the case, as will be afterwards shown, that the whole experiment is made expeditiously enough to neglect the time loss of nuclei due to the normal causes mentioned. Cf. § 4.

In two successive experiments which showed a reasonable order of agreement, the color sequences of the coronas were observed from the center outward, while the corresponding flame or axial colors were simultaneously noted; but here there is an uncertainty from the small relative thickness (30·5 cm.) of the axial layer of water particles. Table I contains the results. Where different colors were seen (which may either be errors of judgment, or real differences of closely contiguous coronas) they are noted by inserting both colors on a line. The colors being fleeting, it is out of the question to wait for rigorous isothermal conditions; neither is it certain that the colors were caught for the adiabatic state of compression. A small allowance of time after exhaustion must be granted for judgment. The general agreement of coronas obtained seemed to vouch for this method of combating, partially at least, an inherent difficulty. The computation will be made both for isothermal and for adiabatic conditions, leaving the true result to be derived below, § 5.

Ignoring decay and similarly spontaneous time losses due to the motion of the nucleus, I here obtain a scale of optical effects related to the nuclei in a given volume of air saturated with aqueous vapor and to the given exhaustions. As more particles are present the condensed water globules are finer, remembering that the medium is always identically supersaturated. Only the momentarily fixed corona following the exhaustion has a real meaning.

The axial color or color of the full flame is seen to make up a similar sequence ahead in phase and nearly complimentary in color to the central patch of the corona. This will be separately investigated below, § 7.

The advantage of a geometric distribution of coronas will appear in the attempt now to be made to remove the time loss, which is also probably geometric.

4. *Loss of nuclei in the lapse of time.*—To determine in how far such an interpretation as given in the last paragraph is admissible and to correct it for the other simultaneous losses, it is necessary to determine the decrease of nuclei when the receiver is left for long intervals as far as possible without exhaustion or manual interference. In the following experiments the time between the inevitable exhaustions (usually about 96 sec., above) is prolonged to thirty minutes or even an hour. The first column in Table II shows the number of the exhaustion (with refilling of filtered air), the second the time elapsed since nucleation, the third the color sequences of the corona obtained. These are as a rule easily recognized by comparison with Table I, and the coronal number or "order" is put in the next column. It may be noted that fogs are often

spontaneously produced without change of pressure. The bearing of this on the present results is chiefly as an error induced by the subsidence of loaded nuclei. The table contains three independent experiments.

Omitting further discussion, one infers from the obviously linear distribution of the orders of coronas in the lapse of time, either that the number of nuclei is not changed by exhaustion, correspondingly greater numbers being produced at low pressures to make good the loss, or more probably that the time losses obey similar exponential laws to the exhaustion losses. The following theory is a more rational systematization of the data in accordance with the latter view, for which other cogent evidence might be adduced.

TABLE II.—Time losses of nuclei. $N = N_0 10^{bt \log y}$

Exh. No.	Time.	Coronas. Colors of successive annuli.	No. by Table I.	b
0	0m	Nucleation	0	·08
1	27	Wh, viol, yl	4	
2	61	Wh, yl, br, gr, rd	8	
3	94	Wh, prp, yl-gr, rd, gr	10	
4	124	Wh, br, gr, rd	14	
5	160	Wh, gr, prp, yl-gr, gr	17	
6	190	Wh, br, gr, rd	20?	
7	292	No color	—	
Series 2.				
0	0m	Twice nucleated	0	·14
1	50	Yl, rd, gr, rd	8	
2	80	Gr, rd, gr, rd	11-12	
3	112	Prp, br, gr, viol, rd	15	
4	140	Wh, br, gr, rd, gr	20?	
Series 3.				
0	0m	Nucleation	0	·10
1	95	Wh, viol, prp, yl-gr, rd, gr	10	
2	155	Wh, prp, br, gr, rd	15	
3	185	Wh, prp, br, gr, rd	19	

Let n be the order of the corona (exhaustion number), N the number of nuclei producing it for the fixed supersaturation. Without correction for time losses, $N=y^n$, where $y=p/p_0$ under isothermal, and $y^{1/\gamma}=p/p_0$ under diabatic conditions, p and p_0 being the pressures before and after exhaustion.

The data of the preceding section show that N suffers a time loss varying as $a+bt$ in the time t, where a and b are constants. Hence the above equation must be corrected to read $N=y^{n(1+bt)}$ to admit of both losses of similar geometrical character. Finally the initial nucleation, $N_0=y^{n_0}$, is not identical in the different experiments, whence

$$N=10^{(n_0+n(1+bt))\log y}$$

is the final form of the equation.

If in two experiments beginning with two different nucleations, N_0 and N'_0, the same corona or N is reached for different times, t and t', and different numbers of exhaustions, n and n', of the same ratio, y, then $N=N'$ and therefore after reduction if for brevity $N_0=1$ and $n_0=0$, $b=(n-n'-n_0)/t'-nt)$. If two identical coronas are reached, the n_0 may be eliminated so that $b=(n_1-n_2)/((t'-nt)_1-(t'-nt)_2)$, where the first identical coronas are seen for N_1, n_1, t_1, and N'_1, n'_1, t'_1, and the next for N_2, n_2, t_2, and N'_2, n'_2, t'_2. The plan is therefore to obtain an even number of identical coronas in cases of Tables I and II, and then to compute b from equidistant groups in the way suggested. Found thus, b is constant for a given table, but varies for the different parts of Table II, for reasons not yet clear. Inasmuch as a correction of Table I is here alone aimed at, it is not necessary to insist on very accurate values, and $b = \cdot10$, a mean value agreeing with the corresponding experiments with the drum below, will be taken. In this way the values N_1 (isothermal, $y = \cdot764$, $t = 1\cdot6$ min.) and N_2 (adiabatic, $y = \cdot825$, $t = 1\cdot6$ min.) were computed.*

5. *Corrected value of N.*—The true value of the number of nuclei lies between N_1 and N_2, nearer the latter. The actual value, N, can be neither one nor the other chiefly because of the accession of heat received from the precipitated water. The rigorous equation would be somewhat complicated; but the computation may be made sufficiently close and perspicuously by the following method of successive approximation.

Let θ and θ' be the original and final absolute temperatures corresponding to the pressures p and p' and the densities ρ and ρ' of the air. We have nearly $(\theta'/\theta) = (p'/p)^{(\gamma-1)/\gamma} = (\rho'/\rho)^{\gamma-1}$ (1). Let S be the entropy per gram of a mixture of vapor and liquid in the ratio of $x/(1-x)$. Then $S = C\ln\theta + rx/\theta$, if C is the specific heat of the liquid, r the latent heat of evaporation. Since $C = 1$, and the mixture is initially all vapor expanding adiabatically, the last equation leads by the aid of equation (1) to $x' = (\theta'/r')(r/\theta + \ln\theta/\theta')$, where $1-x'$ is the quantity of water precipitated per gram of mixture if the heat thus evolved be neglected. Since at 20°C., $\theta = 293°$, $\theta' = 271\cdot2°$, $r = 589$, $r' = 582$, $\gamma = 1.40$, $p'/p = y = 58/76$, the result is $x' = \cdot949$ and $1-x' = \cdot050$ grams.

The next approximation is an allowance for the heat evolved. The air at 20° contains $17/10^6$ grams of moisture per cub. cm., and the amount of water condensed is thus $710/10^6$ grams, the heat evolved $\cdot419$ calories per gram of air. Since the specific

* I have since repeated all these results under better conditions; but the differences need not be instanced here. In case of intense nucleation such as is produced by the sulphur flame, it may require ten exhaustions of the above order y before the initial fogs dissolve into coronas.

heat of air is ·237, for the given values of temperature about 5·17 cal. are absorbed per gram in the adiabatic expansion of dry air. The available calories due to condensation will thus heat this gram 1·77°, which is the correction to be added to θ'.

If the above equation for x' is now again used with the new data, $1-x' = \cdot 046$ grams of water are found for each gram of vapor. Thus $790/10^6$ grams of water are precipitated per cubic centimeter of moist air under the conditions selected in the experiment.

I may note in passing that if 5×10^4 nuclei are present in the saturated emanation (as found in preceding papers), $16/10^{12}$ is the volume of each water particle or about $2 \cdot 5/10^4$ cm, its diameter initially. This agrees very well with the results obtained from the coronas below, § 10.

To find N for Table I, the equation $N = 10^{n\,(1+\delta t)\log y}$ is given by experiment, where y is the ratio of densities before and after exhaustion. Hence, since initially, $\theta = 293°$, $p = 76^{cm}$, and finally, $\theta' = 273°$, $p' = 58^{cm}$, $y = \cdot 819$. Inserting the above value of t and reducing $N = 10^{-\cdot 1007\,n}$. With these constants the values N of Table I were computed.

6. *Relative size of particles.*—Assuming that the same amount of vapor is condensed per cub. cm. in each expansion between fixed pressures of the moist air in the receiver, the relative size of the particles may be computed for the given orders of coronas. If the size of the particle in any one case were known, all would be found absolutely. It is only after about twenty exhaustions that the ordinary normal coronas are encountered. Table I (last column) contains an example of typical cases. It shows that there is not a striking variation of diameters to correspond with the startling variation of coronas. These are thus a rather sensitive criterion of change of diameter of water particles.

Axial colors.

7. *Conical drums.*—It will next be necessary to devise apparatus to show greater intensity of axial color (the colors of the steam jet or color tube), with the necessary relation to the coronas. This was originally attempted with tubular apparatus; but in the interest of homogeneity wide conical apparatus was finally devised, either a single or a double conical drum subserving the purpose. Effective convection currents are then continually in action within, and the density of distribution is uniform, slow work presupposed. With the double drum (apices outward) not only can greater length of column be secured but small end windows of glass suffice. This instrument is thus less troublesome than the single drum, the broad glass base of which, even if thick, is liable to break explosively

after many exhaustions from fatigued elasticity. I shall here quote results for the double drum only. This was about 180^{cm} long and 30^{cm} in equatorial diameter, carefully blackened within to prevent reflection from the sides; for all coronas are advantageously projected against a dull black background. It was made of copper and external ribs obviated collapse. The Welsbach flame is placed at one end, the eye at the other, with appurtenances close at hand for exhaustion and filtration. The end windows were 5^{cm} in diameter. When the axial color is specially to be observed it is best to remove the screen from the mantle and to look at the full extent of the mantle. Ground glass covering the window and illuminated by sunlight is preferable. As these colors are seen mixed with the intense glare of white light, they vanish long before the coronas, and a drum 5 or 10 meters in length will eventually be necessary. With each exhaustion all the preceding colors for smaller water particles are flashed through until the tint hovers over the most advanced of the colors. After this there is a tendency to a retrograde movement, but it soon vanishes. The same difficulty of making observations on these fleeting color contrasts obtains here as above.

The yellows and browns of the first order, which can be produced so splendidly in the steam tube, were not obtained here except perhaps as a retrogression from the blues. The other colors are given in Table III on a plan identical with Table I. Two independent series are shown with the coronal and axial colors of each. The exhaustions are necessarily kept low, which, however, is an advantage, as a more finely graded sequence of colors is obtained. If $N = 10^{\pi(1+b\theta)\log y}$ as in paragraph 4, $y = p'/p = \cdot 888$, and $y^{1/\gamma} = \cdot 919$. The constant b was specially determined and found to be $b = \cdot 092$, agreeing sufficiently with the above to admit of the same value in the corrections. The data are omitted for brevity.

The method of paragraph 5, for computing the actual number of nuclei, N, between the adiabatic and the isothermal numbers, N_1, N_a, when extended to the double drum gives for $\theta = 293°$, $p = 76^{cm}$, $p' = 68^{cm}$, the absolute temperature $\theta' = 283{\cdot}3°$, as a first approximation. Inserting these data with $r = 582$ and $r' = 586$ into the equation for entropy, the approximate value $1 - x' = \cdot 0243$ grams of water precipitated per gram of mixture results. This is equivalent to $\cdot 204$ cal. evolved per gram of air by the precipitation of the available $\cdot 0143$ grams of moisture. The rise of air temperature is thus $\cdot 86°$. Hence the new data are $\theta = 293°$, $\theta' = 284°$, and these with the above values of r and r' give $1 - x' = \cdot 021$ grams. Thus $361/10^9$ grams of water are precipitated per cub. cm. of moist air. If as before 5×10^4 nuclei are present per cub. cm. at the

outset, the volume of each precipitated water particle is $7/10^{12}$ cub. cm. and its linear dimensions $2/10^{4}$ cm.

Finally, if in $N = 10^{n(1+bt)\log y}$, y be computed as the ratio of densities at p, θ, and p', θ', then $y = \cdot 916$; and since $1+bt = 1\cdot 35$ for $t = 3\cdot 5$ min., $N = 10^{-\cdot 512n}$. In this way the values marked N in Table III were computed.

Discussion.

8. *Color sequences.*—The coronal center which corresponds

TABLE III.—Axial and Coronal Colors seen in the Drum.

$y = \cdot 916$; $t = 3\cdot 5^{m}$; $b = \cdot 1$; Exhaustions 76–68^{cm}.

Exh. No.	First Series. Axial color.	Coronal center.	Time.	Second Series. Axial color.	Coronal center.	Time.	$N \times 10^{3}$	$\sqrt[3]{1/N}$
0	—		—			39^{m}	1,000	1·00
1	—		—	Viol-bl	Fog	41	889	1·04
2	Bl		27^{m}	Bl	"	44·5	790	
3	Bl		31	Bl	"	48	702	
4	Bl-gr		35	Bl-gray	Colorless	51·5	624	
5	Bl-gr		38	Yl-gr	"	55	555	1·22
6	Gr-yl		41	Gr-Yl	"	58·5	493	
7	Yl		45	Yl	Olive-gr	62	438	
8	Yl-or		48	Or	"	65·5	389	
9	Or	Olive gr	52	Or	"	69	346	
10	Or-rd	—	56	Or. rd	"	72·5	308	1·48
11	Rd	Gr-yl	59	Prp	Gr-yl	79	273	
12	Viol-rd	—	63	Prp	Gr-yl	79·5	243	
13	Viol	Or-yl	66	Viol	Yl	83	216	
14	Viol-bl	Rd	70	Viol-bl	Or-rd	86·5	192	
15	Bl-gr	Prp	73	Viol-bl	Rd	90	171	1·80
16	Bl-gr	Prp	77	Gr	Prp	93·5	152	
17	Gr-yl	Prp	80	Yl	Prp	97	135	
18	Yl?	Gr	84	—	Wh viol	100·5	120	
19	Prp	Yl-gr	87	Viol?	Gr	104	106	
20	—	Or-rd	91	Viol	Yl gr	107·5	95	2·19
21	—	Gr	94	—	Or-rd	111	84	
22	—	—	—	—	Prp	114·5	75	

to the first axial blues and blue greens of Table III is not determinable as to color in the drum. In the globe it was seen to be a diffuse red-rimmed tawny fog. The first pronounced contrast which appears is the orange-red axial color and the blue-green or green-blue field. This is usually easily obtained and is complimentary in character. The axial colors then move toward the violet and the field colors toward the yellow. After this the axial colors are already nearly white; the tinge of color is so faint that it would be hard to recog-

nize it, if the sequence of colors were not known, from the steam jet. Nevertheless, the march of the axial colors into bluish, greenish, yellowish tints, corresponds to a march of the field from yellows into reds and purples. The colors thus follow each other around the circle, apparently diametrically opposed in position. I have stated that the axial yellows, browns, etc., of the first order were not obtainable in any case, directly.

I made many attempts to strengthen the axial colors by polarized light. The results, though not negative, are not easily interpretable. Thus the purple of the second order passes between crossed nicols with immensely increased saturation. But whether the depolarization is produced within the drum or at the glass windows (which cannot be kept quite clear), or is the result of diffused light entering from elsewhere, I have not been able to determine. These results were particularly marked for columns of about one meter in length.

If the colors for the drum and for the globe be compared for the same axial flame color, the latter will be seen to be about three orders in advance of the other. This is referable to the greater initial nucleation in case of the globe where the exhaustions were greater. It implies, however, that the initial distribution was in all cases undersaturated, if indeed saturation can here be expected. Apart from this, the nuclear ratio is about the same in the two cases so far as can be made out.

There is a final outstanding observation of some importance which needs mention. In studying the time losses I noticed that after long waiting (144 min.), single exhaustions seemed to remove two orders of coronas. Similarly on allowing the apparatus fully nucleated to stand over night (say 17 hours), the first exhaustion next morning showed a faint small but definite corona of the ordinary kind, but on refilling with filtered air, the subsequent exhaustions produced no corona whatever. These results can not be associated with the spontaneous production of nuclei from benzol, for instance. The subject requires further investigation. Water is found to produce nuclei after shaking, and it may be that an electrical influence is at work; but if fresh and at rest, the air above it is usually pure relative to such exhaustions as are here in question.

9. *Time losses.*—Some conclusion must be derived as to the nature of the time loss, which in the above equation has been very fully reproduced (apart from the inevitable errors) by $N = N_0 y^{bt}$, where N is the number of particles per cub. cm., surviving in the receiver after the lapse of time, t: $y = \cdot 825$, $b = \cdot 1$ by experiment. Thus on reduction, if $\beta = \cdot 0083$,

$$N = N_0 10^{-\beta t}. \quad (1)$$

As in my preceding papers, I will suppose that the absorption velocity of the nucleus is k cm./sec., independent of the

density of distribution. Moreover, that in a spherical receiver, nucleated at the time $t = 0$, N nuclei are found per cub. cm. at a distance r from the center. The distribution is in any case concentric, but otherwise disposable at pleasure. Since the absorption of nuclei is supposed to take place at the inner surface of the receiver only, there is a continued flux outward. The solution of the problem requires some understanding as to the manner in which this flux takes place.

(1) If there is a mere motion outward for all particles, the partial differential equation is found to be $d(r^3N)/dt + kd(r^3N)/dr = 0$, of which the integral determined by Lagrange's method is $N = N_0 e^{f(r-kt) - \ln r^3}$, where f is an arbitrary function. This is found for an initial distribution independent of r. The result is clearly not in keeping with the actual case of experiment, as is to be inferred if the nucleus moves in all directions.

(2) The next case would be that of diffusion. The partial differential equation is $d(rN)/dt = k\, d^2(rN)/dr^2$, where rN is zero at the surface and the center and the initial condition is $rN = rN_0$. This equation is integrable in the well known way, but the result again fails to meet the actual condition of the experiment as set forth in the next paragraph.

(3) Remembering that the investigations above were purposely conducted in wide receivers, with the object among others of keeping the contents in a homogeneous state of nucleation through the agency of convection currents, it may be safely assumed that N is not a function of r but of time only. If this were not so the coronas would show color distortion (as they do in marked degree in benzine vapor) as well as the time changes observed. In case of water vapor, the ever present convection will not allow either the distribution (1) or (2) to persist. Hence whatever removal of nuclei takes place at the inner wall of the large receivers is a deduction or drain of nuclei from the *whole* volume of vapor, uniformly. This experimental condition simplifies the computation and offers an easy interpretation of the results obtained. In case of absorption with the adequate convection, therefore (if R be the radius of the receiver), $-(4\pi R^3/3)\, dN/dt = Ak\, 4\pi R^2 N$, where k is the absorption velocity of the nucleus and A a coefficient, stating what part of k is effective in view of the given degree of convection maintained. For mild convection the loss of nuclei at the surface will take place largely by diffusion through relatively fixed layers and A will be a small fraction; whereas in case of very turbulent agitation, as when the nuclei-bearing air is driven through fine bore or capillary tubes, A will be nearly one. The air is soon washed clean of nuclei. Hence (2) $N = N_0 10^{-3Akt(\log)e/R}$, an equation identical in form with that actually found in the experiments.

From equations (1) and (2), $\beta = 3Ak(\log e)/R$; and if $k =$ 18 cm./min., $R=15$ cm., then $A=\cdot001$. Thus the absorption velocity found from these experiments is but 1/1000 of the value found when the saturated emanation is forcibly passed through fine bore tubes less than ·5 cm. in diameter. A correlative result was instanced in my earlier experiments showing the relatively small value of k found in passing the emanation through a wide tube, 5 cm. in diameter, though I was not at the time quite clear as to the reason. With the necessarily small mean free path of the nucleus, which being large in comparison with molecules owes its slow motion chiefly to the unfavorable bombardment of many molecules, the result stated is precisely what is to be expected. It is in harmony with the preservative effects of the dilution of the saturated emanation.

In general, therefore, the absorption velocity of the nucleus depends on the violence with which the contact of the nucleus and the solid boundary is promoted. In a bundle of fine tubes of a given area the absorption is enormous, caet. par., as compared with the single tube of the same area. Nevertheless the value of k seems to reach a superior limit in case of extreme agitation. This maximum of k is the value which I interpreted as being the true nuclear velocity and used with this meaning (after allowing for the motion in all directions) in the interpretation of my electrical experiments.

10. *Estimated size of water particles.*—The rate of subsidence of the fog is not a good criterion* of diameter, because this datum is complicated by the evaporation of water particles (apparent subsidence at the top), and by their inevitable growth, remembering that the coronas are all fleeting phenomena. Some notion of their size, and this an upper limit, may be obtained. If the fog subsides at the rate of 1^{cm}/sec., the radius of the particle will be $r = \cdot0009^{cm}$. For any other velocity expressed in terms of this normal rate, $r=9\times10^{-4}\times\sqrt{v}$. Now the rates are never a small fraction of cm./sec., so that the radii are not liable to be much below say $10^{-4\,cm}$, a datum which at first sight is surprisingly large but is corroborated by the following independent estimates.

It has been shown above that in the case of spheres the moisture precipitated per cub. cm. of air partially exhausted as stated, is 79×10^{-8} grams, and that with 5×10^{4} nuclei per cub. cm. in the saturated emanation, this is equivalent to an initial diameter of the water particles of about $2\cdot5/10^{4\,cm}$. This datum is an order of values like the preceding, whereby two results are to this degree confirmed, viz: the order of size of particles producing axial color and the number of particles estimated for the saturated emanation.

* Air cleared of fog by the warmer walls of the receiver after exhaustion, also rises to the top.

The same method applied to the results obtained from the double drum showed $2/10^{4\text{cm}}$ as the diameter of the particles in the first exhaustions. The smaller size here corresponds to less exhaustion.

A final estimate is obtainable from the size of the normal coronas after say twenty or thirty exhaustions. Estimating this as about twice as large in diameter as the ordinary lycopodium corona, if the particles of the latter measure $\cdot0032^{\text{cm}}$, one may rate the residual water globule at $\cdot001^{\text{cm}}$. Indeed Fraunhofer and Kaemtz's measurements showed particles in lunar coronas as large as $\cdot0017$ to $\cdot0033^{\text{cm}}$, depending on the season. Thus if the final size is $\cdot001^{\text{cm}}$. the initial size must have been $\cdot0003$ to $\cdot0002^{\text{cm}}$, corresponding to twenty or thirty exhaustions. Similar results are deducible from the drum and they are thus again in agreement with the preceding estimates. Finally the normal coronas may be measured absolutely and the dimensions computed from the deviation on diffraction. This is the practical plan with which I am now engaged, and I will therefore waive further discussion.

If the independent estimates just stated be summarized, the data are clearly of an order ten times greater than would follow if the axial colors of the drum or the steam jet were produced by interference of thin plates, granting that the old vesicular theory of atmospheric condensation is disproved. I admit that data as large as those found for the water particles are contrary to my expectations.

11. *Size of nuclei.*—This has been variously estimated by the aid of Kelvin's vapor pressure equation, successively modified by the younger Helmholtz,* and by C. T. R. Wilson.† Naturally the nuclei are supposed to be of the same size and the supersaturation carried far enough to condense water on each. Helmholtz found $15/10^{8}$ to $26/10^{8\text{cm}}$ as the size of his nuclei. Wilson finds $8{\cdot}7/10^{8}$ for the case of rain-like condensation, and $6{\cdot}4/10^{8}$ and $5{\cdot}9/10^{8\text{cm}}$ for cloudy condensation, foggy and colored. The above data for the globe similarly interpreted give $8/10^{8}$ and $18/10^{8}$ as the smallest radii of the nuclei on which condensation takes place.

The small size of the nucleus obtained in this way is startling, but as the method involves a huge extrapolation from the radius of capillary action (say $5 \times 10^{-8\text{cm}}$) almost as far as the molecular diameter, it cannot be received with much confidence and the size of the nucleus must be left in abeyance.

On the other hand, the size of the water particle is sufficiently large to admit of the application of Kelvin's equation. Moreover, there is here a mere accretion of water upon water.

* R. v. Helmholtz, Wied. Ann., vol. xxvii, p. 526, 1886.

† C. T. R. Wilson, Phil. Trans., London, vol. clxxxix, p. 306–307, 1897.

If the change of pressure to pass from a given to a succeeding corona, or to any recognizable change of corona, be determined by two successive exhaustions, the particles of the first corona are the nuclei of the second, and consequently the radius of the former should be determinable absolutely. With this datum for the particles of one corona, Tables I and III would furnish the diameters of all.

Unfortunately this theoretically very promising method breaks down on experiment. For, let a small exhaustion be made adiabatically at the mean pressure, p, and the mean absolute temperature, θ. Then in the modified form of Kelvin's equation for water (density = 1), let the logarithm be expanded. If T is the surface tension of water, p' its vapor pressure, the radius of water nucleus will be approximately, $r=2T/R\theta(\delta p'/p'-\delta p/p)$, (1), where R is the gas constant of water vapor and δ denotes increments. If the condensation takes place near the freezing point, as in the above experiments, we may write $\delta p'/p' = \cdot076\delta\theta$. Again, for the occurrence of adiabatic expansion $\delta\theta/\theta = ((\gamma-1)/\gamma)\delta p/p$. After substituting both results in equation (1) $r\delta p = 2Tp/R\theta(\cdot217\theta-1)$, where δp is an adiabatic increment of pressure, applied to the moist air at θ and p. Using this equation for water particle of the order of dimensions estimated above at $\theta = 273°$ and $p = 76^{cm}$, an exhaustion of but 1/10 millimeter is in question. Now I satisfied myself in special experiments that exhaustion as small as 1^{cm} would be perceptible in color changes of the coronas, particularly in the case of certain higher orders; but the small change corresponding to $\cdot01^{cm}$ is out of the question. I do not see, therefore, that methods other than those based on measurements of coronas will be applicable for the determination of the absolute dimensions.

Pursuing this subject, I found that the coronas of benzol following the initial fogs are all normal, relatively large particles being precipitated at once. Hence, if m be the mass of benzol condensing, computed for given exhaustions as in § 5, and if d be the diameter of the benzol particles found by measuring the coronas, then $N = 6m/\pi d^3$. The number of nuclei active in different methods of nucleation may thus be found by a few exhaustions, compared with the more prolonged observation necessary for water vapor. Care must be taken, however, to make allowance by the same method for those nuclei which I recently found* are spontaneously generated by benzol. I will soon be ready with data bearing on all these questions.

Brown University, Providence, R. I.

* Science, Jan., 1902. With regard to subsidence of nuclei it is well to remember that the same fine clay subsides in water very gradually, but in ether almost tempestuously. A like condition of things may hold for nuclei in relation to the vapors of water and benzol, etc. There is a distinct tendency to agglomerate in the latter case and not in the case of water.

Art. VII.—*On a New Occurrence of Sperrylite;* by H. L. Wells and S. L. Penfield.

Through the kindness of Professor Wilbur C. Knight of the University of Wyoming at Laramie, we have received a specimen of platiniferous copper ore from the Rambler Mine, which is situated in the Medicine Bow Mountains about 50 miles southwest of Laramie. The specimen consisted chiefly of covellite (indigo-copper) with a little pyrite. It occurred to us that the platinum in this ore might exist in the form of sperrylite, $PtAs_2$, since this mineral, which we described* a number of years ago, was found with sulphide ores in the Sudbury region in Canada, and since it has been shown by Walker† that the Canadian sperrylite occurs chiefly in copper minerals; hence we made an examination of the specimen.

About an ounce of the ore was coarsely crushed, decomposed with hot, concentrated nitric acid, and the residue was treated alternately with boiling, strong caustic soda solution and nitric acid until only a very small amount of dark-colored residue remained. When this was freed from a little light-colored material by decantation, about six very small glittering crystals, resembling sperrylite, were observed with the naked eye. After the material had been dried, the crystals were readily picked out on a glass surface by the use of a lens and needle. Under the microscope the crystals showed the wonderful brilliancy of sperrylite. The largest crystal measured $0{\cdot}12^{mm}$ in diameter and was rather highly modified. Although the combination could not be determined with certainty, the forms of the cube and pyritohedron were evidently present. A second crystal was evidently a combination of octahedron and cube. Four crystals having a total weight of about ·00004 grams, assuming that each had a diameter of $0{\cdot}1^{mm}$ which is a generous average, were used for a chemical examination. Upon being heated in the open tube they fused as sperrylite does and gave a sublimate of arsenious oxide in white, octahedral crystals. The residue in the tube was dissolved in *aqua regia*, and the solution, upon evaporation with a little ammonium chloride, gave yellow octahedral crystals of ammonium platinic chloride. There is no doubt, therefore, that the mineral was sperrylite.

We are not sure that the ore does not contain platinum in some other form than sperrylite, but the fact that we did not observe any metallic grains with this mineral makes it probable that all the platinum in the ore exists as arsenide.

* This Journal (3), xxxvii, 67 and 71 (1889).
† This Journal (4), i, 110 (1896).

The discovery that platinum exists in the ores of the Rambler mine is quite recent and of great interest. Professor Knight states* that platinum is found in ores from all parts of the mine in quantities varying from ·06 to 1·4 ounces per ton (·0002 to ·0048 per cent.), and that it is apparently most abundant in the covellite ore. From his account it seems probable that the platinum in this mine will be of considerable commercial importance.

The occurrences of sperrylite in Ontario, in Wyoming, and, as Hidden† has found, in several places in a North Carolina district, show that the mineral is widely distributed on this continent. It is to be hoped that copper ores will hereafter be carefully examined for platinum, and that future discoveries may be made which will tend to alleviate the present threatened dearth of this useful metal.

Sheffield Scientific School,
New Haven, Conn., Jan. 7th, 1902.

* Mining and Engineering Journal, Dec. 31, 1901, p. 845.
† This Journal (4), vi, 381 and 467 (1898).

Art VIII.—*A Cosmic Cycle;* by Frank W. Very.

[Continued from p. 58.]

General Theory of Stellar Explosions.

Three factors enter into the problem of stellar explosive force: (1) Composition, (2) mass, (3) temperature. There must be, first, the presence of substances of an explosive nature and in sufficient abundance; next, a mass great enough to give, at a certain stage of contraction, a gravitationally produced pressure sufficient to bring on the unstable explosive condition. The second condition may therefore be defined more exactly as contraction depending on mass. The third condition—a high temperature—is in one sense an effect of contraction, and might be included in the second; but since the unstable condition cannot exist without powerful internal movements within the atoms, we may designate temperature, and its concomitant latent or internal heat, as the immediate antecedent of disruptive explosions.

Two stages of explosive instability may be distinguished:

(A) That in which the explosive force has sufficient power to rend a star completely into fragments; and

(B) That in which the force is only great enough to cast off fragments of relatively small size from a parent mass.

It is conceivable that condition (A) may be limited solely by the mass of the star, or, on the other hand, that its composition is also an essential. If some of the elements are more highly explosive than others, the unstable ones will be used up first, and afterwards only minor explosions can occur. In view of the variety in the relative stability of compounds, the second view is the more probable; and the following argument seems to be decisive in its favor: Since it is certain that our sun has been attended by the earth during ages of quiet terrestrial development, I shall assume that the sun and stars of its type have entered upon the second stage, which may be distinguished as that of planetary evolution (B), the first stage (A) being described as that of stellar evolution.

Now Mr. Maunder has shown* that, adopting Elkins' parallax, *Arcturus*, which is a star of solar type, if of the same intrinsic brilliancy, must have a diameter 82 times that of the sun; or, taking Mr. Ranyard's more conservative statement, "we may probably feel confident that the parallax of *Arcturus* is less than a third of a second of arc, which would give a distance of at least ten light-years, and a diameter for *Arcturus*, on Mr. Maunder's assumption with regard to its intrinsic brightness, equal to about five times the diameter of the sun."†

* E. W. Maunder, *Knowledge*, vol. xiv, p. 21, 1891.

† A. C. Ranyard, *Knowledge*, vol. xiv, p. 22, 1891.

This gives *Arcturus* a mass 125 times that of the sun, even if its mean density is no greater than the sun's, leading to the conclusion that great mass may still be associated with stage (B), which is therefore determined by the elimination of substances essential to stage (A).

Have we any evidence as to the nature of these eliminated substances? In answer to this question, I must refer to Sir J. N. Lockyer's researches,* which indicate that helium, the metalloids, and some unknown substances, as well as (in a few cases) the substance characterized by the series of spectral lines discovered by Pickering† in ζ *Puppis* (perhaps an allotropic form of hydrogen needing rarefaction and a high temperature for its manifestation), are distinctive of the stars which I have included in stage (A). Hydrogen at its greatest development and the metals belong peculiarly to stage (B). But there must be an intermediate stage connecting the two. Let us suppose that the metalloids are on the whole the most unstable elements and the first to be eliminated, but that before their complete extinction the first stage of condition (B) is entered—that of the Sirian or hydrogen stars (B_1)—and that there is still enough explosive energy left to cast off, but not enough to completely sever from the system such bodies as the major planets. These bodies will retain in their interior substance a larger proportion of metalloids and other light substances, giving them small density, a much more probable assumption than that their composition is the same as that of the earth and their low density due to incandescence, for since the outer planets are on this hypothesis much the oldest, they have long since cooled to terrestrial surface conditions. The abundance of hydrogen in stars of the Sirian type and the presence of hydrogen in the atmospheres of the outer planets may be noted.

(B_2). The next stage in condition (B) is that of the Procyon or hydrogen-iron stars. At this point may be placed the birth of the terrestrial planets whose mean density points to an abundance of iron and metals of similar specific gravity in their interiors.

(B_3). The explosive activity of the sun at the present time is only capable of producing cometary births; and this condition is most favorable to that quiet, continuous sunshine which is needed for life on planetary worlds.

The question: Which are the hottest stars? needs to be put somewhat more definitely. If we ask: Which stars are hottest at the center? the present hypothesis answers that the solar

* "On the Chemical Classification of the Stars," *Proc. R. S. London*, vol. lxv, p. 186, 1899. Not all of the lines designated as unknown are new. "Asterium" is only another name for helium (first subordinate series of "parhelium").

† E. C. Pickering, *Astrophysical Journal*, vol. v, p. 92, 1897.

stars (or possibly even the stars of the fifth division) are the hottest, for there is no probability that the development of heterogeneity has reached its limit. If we ask: Which stars have the hottest photospheres? only conditional answers can be given. We need to know the relation between the photospheric level and the layer of mean density in the cooling gaseous sphere. Which of these layers is most rapidly approaching the center? Is there a gradual change in the incandescent material which forms the photosphere, or are all photospheres alike and formed of one highly refractory substance, perhaps carbon? If the last view is held, it might be surmised that actual photospheric temperatures are closely accordant, and that effective or apparent temperature is an affair of absorption by layers above the photosphere. Since atmospheric absorption in both solar and terrestrial envelopes is greatest for rays of short wave-length, it follows on this assumption that the bluest stars are those whose photospheres are at the highest level, the yellow and red stars being those in which, by condensation and increased heterogeneity, the level of the photosphere has sunk farthest beneath the outer boundary of the stellar atmosphere.

In his Presidential Address before the British Association for the Advancement of Science in 1891, Dr. Huggins has said: "Passing backward in the star's life, we should find a gradual weakening of gravity at the surface, a reduction of the temperature-gradient so far as it was determined by expansion, and convection-currents of less violence producing less interference with the proportional quantities of gases due to their vapor densities, *while the effects of eruptions would be more extensive.*"*

With all of this I can agree, except the words which I have italicized. Convection and explosions are not thus correlated. While a star is expanded, the internal temperature is still relatively low, and viscosity is small enough to permit quiescent convectional circulation which does not interfere with a distribution of gases approximately according to their densities. It is after viscosity has become so great as to impede circulation, and the transfer of deeper superheated matter to the surface can no longer take place quietly, that explosions bring up the denser gases violently and mingle them with the outer layers.

The earlier stages of the helium stars, in my view, belong to the quiescent convectional era, but like the quiescence of a slumbering volcano, there is, during this period, a marshaling of forces preparatory to a final catastrophe. After one or more disruptive explosions, a new stage of somewhat quiescent convection is entered upon in the Sirian stars. But as internal

* *Report B. A. A. S.* for 1891, p. 16.

temperature and viscosity increase, explosions again become frequent or periodic.

There is a limit to temperatures in outer layers immediately below the photosphere, possibly due to viscosity alone, and at any rate partly attributable to this cause. If the photosphere shares in the thermal changes of external layers, we may get some idea of outside temperatures from the distribution of energy in the spectrum. Even if the thermal condition of the photosphere is determined by some physical property which prevents it, for example, from exceeding a certain maximum temperature, and granting that there is a continual action tending to produce this maximum and therefore constant temperature, superficial radiation will always cause the outer layer to fall a little below the maximum, and this the more as the outer atmosphere is more transmissive of photospheric radiation. Allowing for the general absorption of the terrestrial and solar atmospheres, the spectral energy-curve of the sun has its maximum at 0·45 μ, corresponding, by Paschen's law of the wave-length of maximum energy for a black body, to an absolute temperature of 6424 centigrade degrees. It is not likely that the naked photosphere of any star has its spectral maximum much beyond 0·45 μ, but the emissive power of the photosphere may not be that of an absolutely black body, in which case the temperature will be higher.

On the supposition that the photosphere shares the varying temperature of the outer layers, we might have surmised, in the absence of the interlinear comparisons, that the heat in layers near the photosphere would diminish while central temperatures were increasing, viscosity correlating the two. But it is necessary to recognize that we do not know the distribution of energy in the spectrum of the naked photosphere of a star except as revealed by interlinear comparisons, and not even then except by a further correction for general absorption. When these allowances have been made, it does not seem necessary to assume any large variation in photospheric radiation, and it appears probable that there are some special substances which are precipitable in solid or liquid form between definite temperatures, out of which the photospheric clouds are formed, and whose presence serves as an indicator of the level within the stellar sphere at which these temperatures are attained. Thus in the sun, the photospheric level appears to be about 160,000 miles* below the limit of the coronium atmosphere.

Sir William and Lady Huggins in their "Discussion of the Evolutional Order of the Stars,"† suggest that in "the earlier subdivisions of the white-star type, it is by no means certain

* E. W. Maunder, *The Indian Eclipse, 1898*, p. 84.

† *An Atlas of Representative Stellar Spectra*, p. 69, 1899.

that a true photosphere after the pattern of a solar one exists. In these early, and therefore still very diffuse stars, we may see deep down into the star, and the continuous spectrum may come from a thick region of dense gas."

Experiments have been made which seem to show that condensed gases may glow with a continuous spectrum, but the phenomenon is an obscure one and subject to the interpretation that we are not dealing with a pure gas, but that, in some way, complex molecules similar to those of liquids* have been formed by the pressure. We have no examples of such spectra at very high temperatures, and even at low ones gaseous radiation is commonly limited to particular spectral regions, often very narrow, and comes from layers of small depth.†

In another place Sir William and Lady Huggins‡ say: "The progress of contraction of the stellar mass with increasing age will not only exalt the violence of the convection currents, but also increase the density of the gases, though at the same time probably, the nearer approach of the photosphere towards the star's boundary will have the effect of making the increase of density at and just above the photosphere less than it would otherwise be." I have already noted that quiet gaseous convection does not increase with age, but diminishes on account of there being greater viscosity as the temperature rises. In like manner Lane's law that a cooling sun is getting hotter would be a complete paradox, were it not understood that, at a layer of given density, the temperature must always be falling. For a short time the position of a layer of a particular density in a contracting star may travel outwards and at a more rapid rate than the temperature-change in the opposite radial direction at that point; but in the end and throughout the greater part of its history, the position of a layer of given density must travel inwards, and the photospheric layer (which, as we have seen, is possibly at constant temperature, and anyhow does not change its temperature through a very wide range), because it is able to radiate more powerfully than the gaseous layers above it, will increase its distance from the outer boundary, until in the event of final liquefaction of the region below the photosphere, we might expect to find a relatively small nucleus encompassed by a vast atmosphere. After this stage, the nucleus having ceased to contract to any great extent, the gradual condensation of the atmosphere will undoubtedly cause the limiting surfaces in question to approach.

In the scheme which I have outlined there are not two

* See the facts concerning complex molecules of water-vapor and oxygen in my research on "Atmospheric Radiation," *Bulletin G. U. S. Dept. of Agriculture, Weather Bureau*, pp. 99–100 and 103, 1900.

† See F. Paschen, *Wied. Ann.*, vol. li, p. 34, 1894; also F. W. Very, *Atmospheric Radiation*, p. 61.

‡ *An Atlas of Representative Stellar Spectra*, p. 70.

matched classes of solar stars, one on an ascending and the other on a descending scale of temperature, as in Lockyer's classification; but each stage is passed through once for all, and the order of transition is as follows:

(A) Stars typically of great mass but small density.

(A_1) Bright-line Orion stars, but little removed from nebulae. Hot and rarefied, but the heat somewhat uniformly distributed by free convection.

(A_2) Orion stars with narrow dark hydrogen and helium lines. Hot and more condensed, but not to such an extent as to separate an extensive hydrogen atmosphere; moreover, metalloids prevail over metals. All of these may be looked upon as explosive stars, if of sufficient magnitude, giving rise to clusters and extensive nebulae with intimate physical and chemical connection between stars and nebulous matter.

By the subdivision of these stars of great mass, a new stage of quiescent development is begun in which small mass and thence small pressure, with viscosity, prevent disruptive explosion.

(B) Stars typically of smaller mass and of relatively great condensation.

(B_1) Sirian stars. A dense hydrogen atmosphere. Condensation begun, but not yet very great.

(B_2) Procyon stars. More condensed. Interior convulsions begin to bring up denser material and mingle it with the outer layers.

(B_3) Solar type. Still more condensed, and very hot at the core. Complex spectra. Calcium and metals prevail.

(B_4) Stars with unknown flutings of absorption, growing fainter towards the red, indicating the presence of complex molecules. Variable from outbursts of hot luminous gases.

(B_5) Stars with dark hydro-carbon absorption flutings, growing fainter towards the violet. First appearance of compounds. Central condensation probably extreme, and near the limit of possible stellar life.

Stage (A_2) corresponds to McClean's Div. 1, to Lockyer's $A\alpha$ and $A\gamma$, and to Miss Maury's Groups II to V. "The helium stars of Division 1 and the gaseous nebulae are subject to a similar law of distribution in relation to the galactic plane."*

Condensation and development of heterogeneity go hand in hand. Explosive forces, no longer strong enough to disrupt, are gradually resumed in stage (B), and are perhaps responsible for the equally gradual disappearance of hydrogen.

Nebulae and novae are obviously near to (A_1). The Orion stars, as stated, sometimes have bright lines in their spectra, the hydrogen being negatively electrified. In this group come

* F. McClean, *Phil. Trans. R. Soc., London*, vol. cxci, p. 129, 1898.

also such close binaries as *β Lyrae*, in which the separation of the components by excessively rapid rotation, or possibly by rotation and explosion combined, is barely effected.

The evolution of negative hydrogen still continues in our sun; but in the stars of Secchi's third type (McClean's Div. 5)—the long-period variables—positively electrified hydrogen is found whenever bright lines occur. The increasing absorption and its banded character (pointing to molecular complexity), together with the diminished intensity of the shorter waves, indicate that the third-type stars have begun to wane.

Some of the characteristics of stellar childhood recur in old age, but others are entirely different, or even opposite.

Passing from the evidence furnished simply by the light of the stars to that afforded by their consociations, I proceed to apply the theory to the phenomena of binary stars.

Of eighteen stars having spectra of composite type, given by Miss Maury,* the majority have the brighter star of solar type. Holden† finds that among undoubted binaries having components of unequal magnitude, the brighter is usually a yellow, and hence presumably a solar star, while the fainter is a blue or purple, and therefore probably a Sirian star; but some remarkable exceptions exist, and such stars as *Sirius* and *Procyon* prove that no simple rule, depending on rates of cooling as affected by mass alone, can cover all of these cases. This diversity of development in the members of a pair appears to show that, in the first place, fission has occurred after heterogeneity had been established; and, second, that sometimes the larger star retains the greater part of the substances which go to make up a solar star, while in other cases it is the smaller star which has received the denser central parts of the composite mass.‡ This difference of composition must dominate all subsequent evolution.

While heavy materials may be ejected by long-continued explosions of minor intensity from the central into an outer shell, the lighter substances of the outer layers are not carried downward in any corresponding degree. Hence in the separation into a binary, the body composed mainly of deeper substances has been largely freed from explosive material, and is ready to enter upon the more quiescent existence of a solar star; while the companion, consisting principally of material

* Miss Antonia C. Maury, *Ann. Harvard Coll. Obs.*, vol. xxviii, pt. 1, p. 92, 1897.

† E. S. Holden, "Note on a Relation between the Colors and Magnitudes of the Components of Binary Stars," this Journal (3), vol. xix, p. 467. 1880. Professor Holden finds that when binary stars have both members of the same color, the mean difference of magnitude is: B−A=0·53 mag; when of different colors, B−A=2·44 mag. "We do not find *isolated* stars of decided green, blue or purple colors" (p. 468); but contrast tends to an exaggerated estimate of color.

‡ See, however, the suggestion concerning the development of the Algol binaries on p. 105.

from the outer shell which has never undergone the greatest pressures, is still rich in unaltered elements, and contains an excess of elements of small atomic weight and low density. In the majority of stars of composite type, the component formed from the outer shell is the smaller, as if the separation had been that of a comparatively thin layer thrown off by centrifugal force. Where, as in a large number of optical binaries, the luminous intensities are nearly equal and the spectra similar, it is probable that the separation has been due to a central explosion, dividing the original body into two nearly equal portions of similar compositions.

There does not appear to be any distinction of orbital eccentricity in respect to spectral type. If eccentricity were gradually developed from an initial orbit, circular in every case, there ought to be some progressive change of eccentricity with change of type. Since there is none, I infer that eccentricity of stellar orbits is the immediate result of forces involved in a sudden disruption, and has been only slightly modified by tidal evolution.

Dr. See says of the eccentricity that "this element, which depends wholly on micrometrical measures, and is independent of the parallaxes and relative masses of the stars, gives the sole clue to the evolution of the stellar systems, and will some day enable us to lay a secure foundation for scientific cosmogony."* While I cannot make eccentricity the sole clue, it is certainly a very important one, and it seems to me that its indications support the view advanced here. The radial velocities produced by an explosion will be added to those given by tidal interaction of the components of a binary system. The mean orbital eccentricity of about $\frac{1}{2}$, which Dr. See finds for stellar binaries, need not require so long a time for its development as we should infer from the theory of tidal evolution taken alone.

The wide gap separating stellar and planetary orbital eccentricities (0·482 and 0·039 respectively) implies a different origin in the two cases. It is suggested here that the difference is attributable to the mode of division; that in separations occurring through excessive rotation, the division is into very unequal parts; that such rapid rotations imply a considerable degree of preliminary concentration, with imperfect fluidity which is not favorable to equable division, and on the whole are more likely to prevail at later than at earlier stages; that at later stages explosions, while assisting division, become less frequent and less powerful, owing to the elimination of especially explosive substances. On the other hand, division by central explosion may be expected to give more nearly equal components, and ought to be more likely to occur at a

*T. J. J. See, *Evolution of the Stellar Systems*, vol. i, p. 252, 1896.

comparatively early stage of condensation, before the loss of peculiarly unstable substances.

Out of a total of 117 Orion stars (Groups I to V), Miss Maury gives 36 as of Div. *b*, or having hazy lines implying rapid axial rotation. The Sirian stars (Groups VII to XI) show 46 stars in Div. *b*, out of a total of 185 stars.* None of this division occur among the solar stars. If the Orion stars are much more expanded than the Sirian, an equal superficial velocity will not be sufficient to give centrifugal separation at the earlier stage. The Sirian stars are more highly condensed —witness the dense hydrogen atmospheres—and hence are the most likely to give birth to planets by rotary velocity.

That some of the planetary births from stars as late in stellar development as the hydrogen-iron type, may occur by centrifugal expulsion, appears certain. Lockyer obtains for *α Aquilae* a minimum equatorial surface velocity "of about 45 miles per second supposing that the axis is perpendicular to the line of sight."† Considering that this is 34 times as great as the present solar surface rotation, it would not be surprising if some of the hazy-lined stars should furnish us with a new type of novae. That rapid rotation ceases in the solar stage implies that rotational moment has then been destroyed by a previous expulsion of planets.

At present our knowledge of systems in rapid revolution, and therefore presumably young, is confined to Algol variables and spectroscopic binaries. Professor Pickering says: "It is noteworthy that all known variable stars of the Algol class have spectra of the first type, except perhaps R *Canis Majoris*, whose spectrum is either of the first or second type."‡ U *Ophiuchi*, *λ Tauri*, and *β Persei* are helium stars, and the low average density of the Algol variables, from $\frac{1}{3}$ to $\frac{1}{30}$ that of the sun,§ points to an early stage of condensation as normal in stars of the Orion type. It must also be presumed from the short period of the Algol variables that the separation of the components can be but little beyond Roche's limit, and consequently that these bodies are at a very early stage of stellar evolution. Since the eclipsing body is invisible, or at best a red star (U Cephei), there must be either a great diversity of composition or an entirely different life-history for the components of an Algol variable. This diversity does indeed suggest a capture theory, but the small eccentricity of the Algol-type orbits is decisive against such a supposition. The eclipsing body cannot be a meteor-swarm, or a companion disrupted by tidal strain, for only a single body of regular figure

* Miss Antonia C. Maury, *Ann. Harvard Coll. Obs.*, vol. xxviii. pt. 1, p. 10.

† J. Norman Lockyer, *Proc. R. Soc. London*, vol. lxvi, p. 237, 1900.

‡ E. C. Pickering, *4th Annual Report of the Photographic Study of Stellar Spectra, Henry Draper Memorial*, p. 5, 1890.

§ H. N. Russell, *Astrophysical Journal*, vol. x, p. 317, 1899.

and defined limits could give the exactly timed and sharply defined occulations observed. Moreover the two bodies do not differ greatly in size or in mass. A dark meteor-swarm would have an extent relatively much greater than a stellar body of nearly the same mass. Considering their great mass and close proximity to the primary, the obscurity of these companions remains one of the most singular facts known to astronomy. The best explanation that has occurred to me is that the companion originally separated as a complete annulus and remained long enough in the annular form to cool by reason of the extensive radiating surface, before the ring was disrupted and its material gathered into one body.

The difference of type is much less in stars of composite spectra, which, however, are not necessarily binaries. Dividing the recently discovered spectroscopic binaries into two groups, one for periods of only a few days, the other where the period is several months, I find the following distribution by spectral types, according to the divisions of McClean and the groups of Miss Maury, omitting several pairs whose periods remain unknown.

Spectroscopic Binaries of Short Period.

Star.	Spectrum Div. or Group.	Variation of Velocity.
A. G. C. 10534*	?	610 km.
12 Persei	Div. 3 (Group 11)	51
μ' Scorpii	" 1a	460
β Aurigae	" 2 (" 8)	240
α Urs. Min.	" 4 (" 13)	6
η Aquilae	" 3 (" 12)	50
ζ Geminorum	" 4 (" 14)	27
κ Pegasi	" 3 (" 12)	79
ζ Urs. Majoris	" 2 (" 8)	156
ω Draconis	" 3 (" 11)	71
θ Draconis	" 4 (" 13)	50
o Leonis	" 3 (" 12)	97
λ Andromedae	" 4 (" 15)	18

Mean variation of velocity = 147 km.

Spectroscopic Binaries of Long Period.

Star.	Spectrum Div. or Group.	Variation of Velocity.
β Capricorni	Div. 4 (Group 14)	40 km.
α Aurigae	" 4 and 3	51
ξ Urs. Majoris	" 4 (" 14)	14
β Scuti	?	21
η Andromedae	" 4 (" 15)	28
χ Draconis	" 4 (" 13)	36
β Herculis	" 4 (" 15)	11
η Pegasi	" 4 (" 14)	23

Mean variation of velocity = 28 km.

* V Puppis.

It will be seen that the short-period spectroscopic binaries are generally of earlier spectral type and have greater variations of velocity in the line of sight.

It has been found that the large and irregularly diffused nebulae, as well as the star-clusters, congregate in or near the Milky Way. This remarkable fact has hitherto been without explanation, but it receives one if we admit that both the diffuse nebulae with their branching and curved extensions, and the clusters, which in several instances exhibit irregularly radial linear arrangements of stars, have been produced by the explosion of exceptionally large stars which are consequently most numerous in the Galaxy. May we not say that here also extremes meet, since the presence of a considerable number of these huge explosive stars implies, apparently, an equal preponderance of unusually small stars, the fragments of past explosions?

The appearance of rotation in nebulous forms cannot be reconciled with any other than a motion of a relatively temporary character. It is inconceivable that these long curved arms should retain even their partial symmetry through any considerable number of consecutive revolutions. They would surely become drawn out and inextricably entangled, if compelled to follow the mazes of such movements as occur in binary stars. This accords with the failure to find any change of position-angle in the nebulae.*

In the absence of proper motion, the combination of motions arising from explosive and centrifugal forces will produce in the disseminated material a symmetrical sigmoid curvature, such as we see in G. C. 3614 = N. G. C. 5247, and with less perfect symmetry in Messier 99,† and in Messier 83,‡ where there are three or four branches to the spiral.

In the absence of rotation, a straight ray of nebulosity may be produced as in

N. G. C.	676 =	G. C.	400
"	4216 =	"	2806
"	4861 =	"	3340

The first of these has a central star, the second a central condensation, and the third two end stars.

Extreme vigor of rotation and repeated explosions are indicated in such complex forms as the great spiral nebula in Canes Venatici.§

According to a sketch made by Mr. Johnstone Stoney with Lord Rosse's telescope, April 19, 1849,‖ N. G. C. 4631 exhibits

* See Dr. J. L. E. Dreyer in *Monthly Notices R. A. S.*, vol. xlvii, p. 412, 1887.
† G. C. 2838 = N. G. C. 4254.
‡ G. C. 3606 = N. G. C. 5236.
§ Messier 51 = G. C. 3572 = N. G. C. 5194.
‖ See *Phil. Trans. R. Soc. London*, vol. cxl, pl. 37, fig. 9, 1850.

a helical structure, something like a variously twisted rope, suggesting that it may have been produced by an explosion directed, by exception, along the axis of a rotating body.

The circular form of planetary nebulae and the presence of a single star at the precise center of a circular nebulous spot are sufficient indication of central forces in these objects, but it has perhape been too hastily assumed that the forces are always centripetal. The recent discovery of a radial structure in certain planetary nebulae lends to these forms also the similitude of an explosive phenomenon.

The sudden dispersal of intensely heated matter through a large volume may be expected to produce by expansion either a mass of relatively cool gas or a cloud of dust. In either case, the dispersal is incomplete, because modification of motions by internal collisions prevents the escape of any considerable number of particles from the central control.

The case is otherwise if the explosive subdivision has been into a comparatively small number of distinct bodies, where the central control may be insufficient to prevent the wandering of the members to such distances that the system is eventually completely broken up.

The existence of a few stars of exceptionally great mass and late type is an objection which may be urged against the proposed theory. It seems possible to meet this objection as follows: In case the explosions resulting in the formation of a planetary nebula have eliminated most of the especially explosive material, we may surmise that a repetition of the condensation of the diffused matter will give a stable star of enormous size.

It may be granted that quasi-fluidity of a meteoric swarm, produced by internal collisions,* supplies a needed analogy for the explanation of certain figures observed among the nebulae, resembling those of the fluid masses freed from gravitational control, which have been made known to us by Plateau, where the interaction of pressure from fluid surface-tension and rotary forces give a number of similitudes; but the existence of these simple forms among the nebulae only emphasizes the necessity for additional hypotheses to explain the numerous departures from forms which may be regarded as cases of simple rotary equilibrium; and the radial and branching features of a great number of nebulae require that the added force shall act radially and outward from a center.

The hypothesis of planetary genesis by nebular annulation through excessive rotary velocity is beset with difficulties.

* See the mathematical researches of G. H. Darwin, "On the Mechanical Conditions of a Swarm of Meteorites, and on Theories of Cosmogony," *Proc. R. S. London*, vol. xlv, p. 3, 1888. *Phil. Trans.* R. S, vol. clxxx. A, p. 1, 1889.

There is not a single example of a nebula with the requisite difference of velocities in the line of sight. The lines in the spectrum of a nebula are comparatively narrow. On the contrary, there are *stars* with all of the spectral lines broad and hazy, indicating large rotary velocities.

The small eccentricity of the planetary orbits forbids the supposition that the planets have been thrown off from the sun by an explosion pure and simple. Excessive rotary velocity of the parent body is necessary to account for the zodiacal and nearly circular paths of the planets. Extreme velocity of rotation would not be expected in an immensely extended and excessively attenuated nebula, but might increase from a feeble beginning after concentration into a condensed nucleus. The requisite rotary velocities, as we have just seen, are found to be associated with the stellar stage of development. Moreover the densities of the most rapid Algol binaries, which, by the present hypothesis, have only recently passed the epoch of stellar subdivision, and may be verging upon the condition requisite for planetary formation, while smaller than that of the sun, are not so small as to indicate any approach to the nebular state.

We have already seen that associated nebulae may be explained as resulting from the dispersals accompaning explosive disruption, and, besides, none of them indicate any orbital motion such as we should expect if they had been separated by centrifugal force. Consequently the planets seem to have developed from the sun after it had reached the stellar condition which is not likely to occur with a density much less than $\frac{1}{50}$ that of the present solar stage, if we may judge from the probable densities of the Algol binaries. But this requires a body of much larger mass than is now possessed by the sun, if its volume is to reach dimensions comparable with the orbits of the outer planets. A certain amount of recession of a planet from the sun may result from tidal interaction while the planet is fluid and near the central body, but this cannot account for the actual distances.

"A numerical evaluation of the angular momentum of the various parts of the solar system will afford the means of forming some idea of the amount of change in the orbits of the several planets and satellites, which may have been produced by tidal friction." "From the numerical values so found, it is concluded that the orbits of the planets round the sun can hardly have undergone a sensible enlargement from the effects of tidal friction since those bodies first attained a separate existence."*

*G. H. Darwin, *Nature*, vol. xxiii, p. 389, 1881. See also *Trans. R. S. London*, vol. clxxii, p. 527, 1881.

There remains the possibility of planetary recession through the destruction of the matter of the sun? With a mass 100 times greater than now, a density of $\frac{1}{5^0}$, a mean radius of $7\frac{1}{2}$ million miles, and an equatorial radius at the epoch of annulation of 10 million miles, corresponding to one rotation in $1\frac{1}{4}$ day, a planet might be produced contrifugally whose distance would increase from 10 to 100 million miles as the material of the sun wasted. This would account for the earth, but not for the major planets, and we have no conclusive evidence that stars of such great bulk exist.

Another alternative remains. Abandoning the conception of low density, and demanding only a sufficiently rapid rotation, which is most likely to occur in a star of considerable concentration, an explosion of minor intensity at an epoch of great rotary velocity, acting radially in the equatorial plane, since centrifugal force makes this the direction of least resistance, may generate by the composition of a radial with a rapid rotary motion a long-drawn-out spiral trajectory, leading to an ultimate nearly circular orbit. This view coincides with the original cosmological suggestion of Emanuel Swedenborg,* although he failed to discern any sufficient reason for the outward progression of the planets along spiral paths to their present orbits. I have been led to this view by a process of elimination, abandoning one hypothesis after another on account of their conflict with known facts. Again there is

* Swedenborg's *Principia* was published at Dresden and Leipsic in 1734 in Latin. There is an English translation by the Rev. Augustus Clissold, London, 1846. As this work seems to be unknown to most astronomers, I will quote a few passages from Part 3, Chapter 4: "Reason dictates that the planets must derive their origin from causes, in time and in place; that causes are to be found in first principles; in fine that the earths in our system must have had an origin by succession." "That the sun is the first moving power in its universe." "That the planets had their origin near the sun." That a "crust, consisting of fourth finites, which is formed around the sun, is rotated in a certain gyre." "That the solar crust, being somewhere disrupted on the admission of the vortical volume, collapses upon itself; and this toward the zodiacal circle of the vortex, or conformably to the situation and motion of the elementary particles, so that it surrounds the sun like a belt or broad circle; that this belt, which is formed by the collapse of the crustaceous expanse, gyrates in a similar manner, removes itself to a farther distance, and by its removal becomes attenuated till it bursts, and forms into larger and smaller globes, that is to say, forms planets and satellites of various dimensions, but of a spherical figure." "That these bodies, separated into globes, consist of fourth finites; that they direct their course into the vortical current according to their magnitude and weight; that they continue more and more to elongate their distance from the sun, until they arrive at their destined periphery or orbit in the solar vortex, where they are in equilibrium with the volume of the vortex."

The part of the theory which predicates a vortex circumfluent to the sun and including the remotest planet, has hardly any superiority over Descartes' conception, but the idea of a derivation of the planets from the sun by centrifugal force of the rotating volume was original, and constituted a momentous new departure in scientific doctrine.

general agreement with the fundamental principle that explosions are prime factors in cosmic development.

After each separation of a planet by combined explosive and centrifugal force, the solar rotation is reduced until gradually restored by contraction of the cooling sun, when the process may be repeated. If in addition there is a gradual destruction of the solar substance, there is another factor producing recession, and one which acts at every distance. If this destruction of matter has continued throughout the solar history, and if the earliest planets have endured proportionately longer and have been proportionately more subjected to the resultant change of distance, these will depart most widely from an equable distribution, depending upon the alternation of periods of increasing rotary velocity due to contraction, and sudden slowing of rotation by explosive overthrow; and the oldest planets must have proportionately greater distances. In this way the departures from Bode's law may perhaps be explained, the law itself being an expression of the relation between contraction of the superficially cooling sphere, increasing angular velocity, and explosive epochs depending on the attainment of a critical stage of partial release from equatorial pressure by centrifugal force.

It has been generally recognized that some other origin of a nova then that of intersecting meteor streams may be found. In the light of the evidence of cosmic explosions which has now been accumulated, I wish to suggest that in the novae we have the very thing sought—the actual disruption of a star by a tremendous central explosion, and the dissipation of its substance in a great cloud of gas and meteoric dust. This partly reverses Lockyer's hypothesis. The meteor-swarm is subsequent instead of immediately antecedent to the nova. An explosion of such gigantic magnitude cannot be absolutely instantaneous. Initial velocities approaching 1000 kilometers per second are recorded. Thus *Nova Aurigae* exhibited a velocity of 800 kilometers per second in February 1892. After the revival of luminosity in August 1892, a velocity of − 225 kilometers per second was measured, and in August 1893, this had diminished to − 71 kilometers per second. The gaseous streams must have reached three times the distance of Neptune in a year and a half. It is possible that a measure of the radius of the resultant planetary nebula may some time give us the distance of a nova.*

All of the novae show the same general sequence of phenomena. The sudden release of superheated interior sub-

* Since this was written (April, 1901), the formation of a nebula of considerable size and rich in structure around *Nova Persei* 1901 has lent new interest to this suggestion.

stances from the depths of the star gives a continuous spectrum of extraordinary brilliancy, rich in the shorter waves, which rapidly passes into a spectrum of the Orion type with narrow dark lines of hydrogen and helium. This is followed by an enormous evolution of hot gases. The complex banded structure of the broad bright F line indicates radiation from a number of streams moving with different velocities.* The great breadth of the lines may mean that the gas is under great pressure, or in a condition such as might be expected if intensely heated matter from the depths of a star has been opened to view by disruption.

This view of the case has been partly anticipated by Professor W. H. Pickering, although he has not predicated so profound a disturbance as the actual disruption and dissipation of a star. Assuming that the phenomenon is produced by gaseous eruptions, he says: "Prominences upon an enormous scale burst forth, spreading in every direction, and completely enveloping the star upon all sides. When they first appear, they present a spectrum of bright lines, but in a few hours the gases first emitted have receded to a considerable distance from the star, and have cooled down owing to the rapid expansion involved in their recession." "This cold advancing atmosphere produces a series of dark absorption lines." "The hot receding prominences, however, ... give out a light whose wave-length cannot be absorbed by the cold advancing atmosphere. They therefore shine with their full brilliancy."†

It is notable that every nova which has been examined spectroscopically at the proper stage, has exhibited this sequence:

1. An intensely bright continuous spectrum rich in violet light.

2. Paired dark and bright lines of hydrogen, etc., the dark lines on the violet side indicating approach, the bright on the red side showing recession. The lines are very broad, denoting either great pressure or a wide range of velocity in the line of sight.

3. Fading of the continuous spectrum, produced by cooling of photospheric clouds until these are entirely dissipated, leaving:

4. A purely gaseous spectrum. Pressure and differential velocity diminishing until nothing is left but a planetary nebula whose light may be due to collisions of meteorites, crystallized out of the expanded and cold gases, perhaps aided by some kind of electric or cathode discharge along filaments or sheets made up of discrete particles.

* M. H. Deslandres, *Comptes Rendus*, vol. cxxxii, p. 620, 1901, notes the composite character of the bands in the spectrum of *Nova Persei* 1901, and assigns velocities of approach of — 1200 ^{km}, — 1600 ^{km}, and — 1850 ^{km}, for three strongly marked divisions.

† W. H. Pickering, *Astronomy and Astrophysics*, vol. xiii, p. 201, 1894.

In favor of this view, I note that there has never been a recurrence of a nova. The blaze is final. These stars all appear in the Milky Way, the locus of the youngest or explosive stars.

The phenomenon in its successive phases has somewhat the same sequence as a volcanic eruption. There are preliminary symptoms leading up to a climax. The violent commotion at the center of the star at first produces nothing but increased superficial circulation, exposing fresh heated surfaces of great brilliancy, but as yet with little accompanying outburst of gas, and with slight velocity in the line of sight. By the time the eruption has become fairly started, the inertia of the outer layers has been so far overcome that rapidly moving streams of gas break through to the surface, and carrying everything before them, launch out into space. For a short time the turmoil is tremendous. Velocities of every degree from excessive positive to extreme negative are met, but tending to particular values along certain streams where the chief part of the motion resides. Some portions of matter, having lost their velocity through friction and interference, are left by the way and expand to comparative coolness, giving fine absorption lines.

The broad paired dark and bright bands, in the order of intensity, belong to hydrogen, calcium, helium, the substance which gives the bright blue band in the spectrum of the Wolf-Rayet stars, magnesium, sodium, nebulum, and others of less intensity. It is essentially a chromospheric spectrum, passing by successive repressions into that of a nebula. The original motion dies out by being frittered away through friction.

Antecedent Stages of Stellar Growth.

The invisible preparation for a new star is probably of excessively long duration, involving the gradual growth of meteorites from innumerable centers of crystalline aggregation, the slow beginnings of movement under gravitation, and at last the clustering of meteor-swarms; but the bursting forth into full stellar life is comparatively sudden, although possibly not attained without more than one fluctuation. The link between nebulæ and novæ is demonstrated. As just stated, we have no example of the recurrence of a nova. It is hardly possible that vast interpenetrating meteor-swarms should pass through each other, attaining stellar temperatures by collisions, without experiencing a change of motion, perhaps becoming associated in orbital connection, in which case the collisions might be expected to recur with increasing frequency until the nova became a permanent star; but nothing of the sort takes place.

The speed of the meteors being very great, the temperatures

given by destruction of motion through impact would be high, and in this respect Lockyer's meteoritic hypothesis, as applied by him to the novæ, agrees with the facts. Moreover, this intense incandescence is immediately followed by a rapid refrigeration which demonstrates that the subsequent history is that of the cooling of relatively small masses. A single body of solar dimensions, raised to a temperature of the same order as that of the sun by a collision, or by any other mode, could not cool to invisibility in a few days. The flaming out of a nova is sudden. Its subsequent fading and passage to a nebula, or to invisibility, is to be attributed, on Lockyer's hypothesis, to the recession of the colliding swarms; and the cessation of high-speed impacts, together with the retention, at least for a time, of internal disturbances due to the previous collision, seems competent to explain the nebulous illumination. But there is no place in this scheme for the actual sequence of spectral changes. If produced by the meeting of meteor-swarms, the nova ought to begin as it ends. The first collisions of sparsely distributed outlying members of the swarm should give a spectrum of bright lines; these should increase in brilliancy, the continuous spectrum and greatest intensity occurring near mid passage, while the densest parts of the swarm are in mutual collision. The sequence is entirely different, and points to a sudden liberation of imprisoned forces, and to control from a fixed center, the relative velocities being none at all at first, but increasing to extraordinary proportions at the height of the episode. There may have been a meteor-swarm anterior to the nova, but, if so, it had already condensed, and it was a single body. It is possible that the darkness of a nova, before the outburst of intense light, may be caused by dense swarms of relatively cold meteors which have not yet coalesced with their primary, and which obstruct its light until dissolved in the final blaze.

The spectral relations of the new stars are with the bright-line helium stars, with which the Wolf-Rayet stars are connected through the spectrum of the principle example, γ Argus,* which, in addition to hydrogen and helium (either dark, bright, or doubly reversed), shows Rydberg's principal line of the supposed new or proto-hydrogen spectrum in the blue at $\lambda=4688$, bright and with a breadth of 20 tenth-meters, also a very bright blue band of unknown origin at $\lambda=4655$, with a breadth of 30 tenth-meters.

* See F. McClean, *Proc. R. S. London*, vol. lxii, p. 419, 1898.

[To be concluded.]

ART. IX. — *Studies of Eocene Mammalia in the Marsh Collection, Peabody Museum;* by J. L. WORTMAN.

[Continued from page 46.]

Family Oxyænidæ Cope.

WITH the Oxyænidæ we enter upon the consideration of a group of the Creodonta in which the teeth had already made considerable progress towards the more typical sectorial structure, even at the beginning of the Wasatch, in which deposits their remains are first met with. This family is represented in this horizon, as far as now known, by the single genus *Oxyæna* Cope, containing two, or perhaps three, well-marked species of fairly sizable dimensions. No species that can be placed ancestral to it have as yet been found in either of the older Torrejon or Puerco Beds, and it would appear probable that they were migrants from the north or from Asia, along with the Artiodactyle and Perissodactyle Ungulates, the Primates, certain of the Carnassidents, including the Felids and Canids, the Rodents and others, at the beginning of the Wasatch epoch. These two or three species appeared simultaneously at all the localities of the Wasatch, in the Big Horn, Bear River, and San Juan Basins, and this fact of itself would seem to indicate a very general and widespread distribution.

The probable immediate successor of the genus in the Wind River deposits is a species which Cope referred to the distinct genus *Protopsalis;* but I have pointed out* that this genus, as far as at present known from fragmentary remains, does not differ materially from one of the Bridger representatives which Leidy described under the generic title of *Patriofelis.* It should be borne in mind, however, that this Wind River form is known from a few fragments only, and it will be somewhat surprising if, when its osteology is more completely known, it does not exhibit a stage of development intermediate between *Oxyæna* and *Patriofelis.* In the Bridger, the main *Oxyæna* line is continued in the two species of *Patriofelis*, large, powerful Creodonts in which the teeth had become much specialized and reduced in number, in a manner not dissimilar to that of the Felids. In this stage also appears suddenly, without any known forerunners in any older formation, a less distinctly specialized type, *Limnocyon* Marsh, in which the teeth are more generalized than in *Oxyæna.* The genus is represented by three or four well-marked specific modifications, one of which persisted to the close of the Eocene, in what I have

* Bull. Amer. Mus. Nat. Hist., 1894, p. 130.

described* as the genus *Oxyænodon*, from the Uinta. In this group, the species are of uniformly smaller size, one of which is among the smallest of the known Creodonts, and all of them, as far as I am at present aware, are characterized by shallow, remarkably thick jaws, provided with a disproportionately large symphysis. A single species of a closely allied form was described by Filhol from the Phosphorites of Quercy in France, under the name of *Thereutherium thylacodes*. This species is the latest and most specialized of the *Limnocyon* series, since, according to Filhol's figures, the last superior molar is much reduced, the first premolar has become single-rooted, and the internal cusp of the trigon in the lower molars has disappeared.

It will be observed, therefore, that we have in this family two distinctive series or lines of descent, one beginning in *Oxyæna* and culminating, according to our present knowledge, in *Patriofelis*, as I have already very fully pointed out,† and a second series beginning in *Limnocyon* and terminating in *Thereutherium*. These two series I choose to regard as two distinct divisions or subfamilies, which may be designated, according to the characteristic genera, the Oxyæninæ and the Limnocyoninæ.

Owing to our imperfect knowledge of the osteology of the Limnocyoninæ, the definition of the Oxyænidæ cannot be very fully given at present, but the teeth are sufficiently known to afford very good grounds for distinction from the other families of the Creodonts. I define it upon the dentition as follows:

Two subequal tuberculo-sectorial lower molars, in which the internal cusp of the trigon and the tubercular heel progressively decrease in size or disappear in the later forms; second inferior molar slightly larger than first; two superior molars, of which the last is transverse when present, but becomes small or disappears in advanced stages of evolution; most highly developed sectorial teeth consisting of first molar above and second molar below, but fourth premolar above and first molar below also sectorial; two external cusps of first superior molar tending to unite, and internal cusp becoming reduced or disappearing in advanced forms, as in Hyænodontidæ.

The two subfamilies may be distinguished by the following characters:

Lower jaw of considerable vertical depth and not especially thickened from side to side; symphysis not particularly enlarged; fibula not articulating with calcaneum, and trochlear surface of astragalus ungrooved, with head very oblique. Oxyæninæ.

* Bull. Amer. Mus. Nat. Hist., June, 1899, p. 145.
† Bull. Amer. Mus. Nat. Hist., 1894, p. 163.

Lower jaw shallow and relatively very thick from side to side; symphysis much enlarged; fibula articulating with calcaneum (*Limnocyon*); astragalus considerably grooved, and head with comparatively little obliquity. Limnocyoninæ.

Subfamily Oxyæninæ.

Of the first of these two subfamilies, as already remarked, there are two known genera *Oxyæna* and *Patriofelis;* but it is not improbable that a transition or annectent form between these two will be found in Cope's Wind River *Protopsalis tigrinus.* It appears to be more or less doubtful whether we yet know the exact lines of specific descent in this group. As at present constituted, the genera may be distinguished as follows:

Dental formula, I.$\frac{3}{3}$, C.$\frac{1}{1}$, Pm.$\frac{4}{4}$, M.$\frac{2}{2}$; second upper molar present, transverse; internal cusp of first upper molar distinct; second lower molar with internal cusp and heel. *Oxyæna.*

Dental formula, I.$\frac{3}{3}$, C.$\frac{1}{1}$, Pm.$\frac{3}{3}$, M.$\frac{1}{2}$; second upper molar absent; internal cusp of first superior molar vestigial; second lower molar without internal cusp and with vestigial heel. *Patriofelis.*

Patriofelis ferox Marsh.

Patriofelis Leidy, Proc. Acad. Nat. Sci. Phila., 1872, p. 10:
Limnofelis ferox Marsh, this Journal, August, 1872, p. 10, Separata;
Limnofelis latidens Marsh, this Journal, August, 1872, p. 10, Separata;
Oreocyon latidens Marsh, this Journal, November, 1872, p. 406;
Patriofelis ferox Wortman, Bull. Amer. Mus. Nat. Hist.

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FIGURE 65.— Portion of left lower jaw, with last lower molar in place, of *Patriofelis ferox* Marsh (type of *Limnofelis ferox* Marsh); three-fourths natural size. (Type.)

The type of this species, figure 65, consists of a fragment of a left lower jaw bearing the last lower molar, together with some few fragments of the skull, vertebræ, and ribs. Professor Marsh said of it in his original description, "The tooth preserved resembles the corresponding one of the lion in its general shape, but is proportionally broader anteriorly, the base of the crown being subtrilateral in outline, with the inner side the longest." This brief description gives the main characters of the specimen very accurately, but it is important to note that more complete specimens have shown the tooth in question to be a second molar; it is not, therefore, strictly homologous with the sectorial lower

molar of the lion, which is the first. This fact, however, was impossible of determination from the fragmentary specimens known at the time Professor Marsh's description appeared. The crown is composed of an anterior and posterior cusp, which represent the external and anterior cusps of the trigon, respectively; of these the posterior is broken away, but it is evident that they were laterally flattened and drawn out upon their edges so as to form a pair of effective blades, as in the sectorial molar of the Felidæ. The internal cusp of the trigon has completely disappeared, and the heel is represented by a mere vestigial spur.

The second specimen of this species was at first referred by Professor Marsh to a distinct species, *Limnofelis latidens*, together with the lower jaw of the immature individual already considered under the head of *Ælurotherium*. He subsequently removed it, using the present specimen as the type, to the distinct genus *Oreocyon*, which he established for its reception. It is now evident, however, that this species is the same as *Limnofelis ferox*, and the name *Oreocyon latidens* therefore becomes synonymous with *Patriofelis ferox*.

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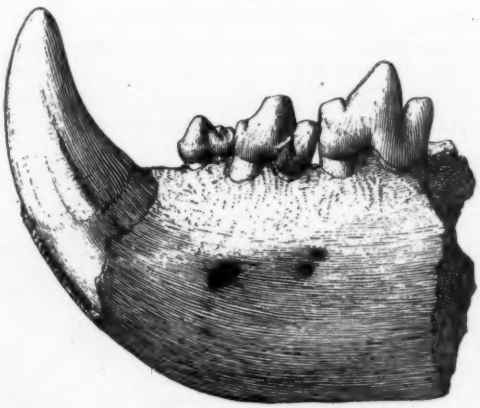
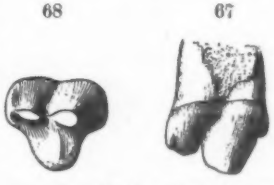


FIGURE 66.—Anterior part of lower jaw of *Patriofelis ferox* Marsh (type of *Oreocyon latidens* Marsh); side view; three-fourths natural size.

The specimen, figure 66, consists of the coössified anterior part of both mandibular rami, carrying both canines, the alveoli, and most of the roots of the incisors, the three premolars upon the left side, and the first and second premolars upon the right side. There are, in addition, some fragments of the posterior portions of the jaw, including a condyle, a well-

preserved superior premolar, probably the fourth, and the greater part of the right humerus.

The jaw is deep and the symphysis strong and heavy. The two rami are firmly coössified, but traces of the suture are plainly visible. The canines are large, somewhat laterally compressed at the base, with a recurved pointed crown. The incisors are two in number upon each side, one being placed almost directly behind the other; their roots are much compressed from side to side and they are relatively small. The first premolar of the series, which corresponds with the second of *Oxyæna*, is a two-rooted tooth implanted obliquely to the long axis of the jaw; its crown is made up of a single pointed anterior cusp, to which is added a broad posterior heel bearing a minute cusp in the center. The second premolar is similar, with the exception that there is a distinct anterior basal cusp and the heel is thrown up into a more or less cutting ridge. The third premolar is considerably larger than the two in advance of it, but the crown is composed of the same elements as that of the second. The superior premolar, figures 67, 68, which presumably corresponds with the fourth of *Oxyæna*, is a three-rooted tooth; its crown is composed of two external and one internal cusps. Of the two externals the anterior is the larger, of a more or less conical form, having its posterior edge produced. The posterior is blade-like and smaller. The internal cusp has a thick rounded form, and is supported by an independent root. The structure of this tooth may therefore be said to be distinctly sectorial.



FIGURES 67, 68.—Fourth superior premolar of *Patriofelis ferox* Marsh (type of *Oreocyon latidens* Marsh); outer and crown views; three-fourths natural size.

Numerous other more or less fragmentary remains of this species are contained in the collection, but as they do not add anything to a knowledge of the osteology, which I have already described in considerable detail from the unusually complete skeleton in the American Museum,* their consideration may be here omitted. It is a source of some satisfaction to note that the conclusions which I reached from a study of the rather fragmentary and imperfectly preserved teeth are herewith completely verified.

In my somewhat exhaustive treatise upon this subject, I was led to express the opinion that these animals were plantigrade, and probably aquatic in habit, pointing out at the same

* Osteology of Patriofelis, a Middle Eocene Creodont, Bull. Amer. Mus. Nat. Hist., May, 1894.

time their relationship with the modern Pinnipedia, the derivation of which may perhaps be traceable to some member of the Oxyænidæ. In a paper recently published, Professor H. F. Osborn has dissented from these views, and expressed the opinion that these forms were terrestrial or arboreal in habits, and subdigitigrade* in gait.

I shall proceed, therefore, to an examination of the paper in detail, and shall first consider a method there presented, by means of which we are said to be able to determine with infallible cer-

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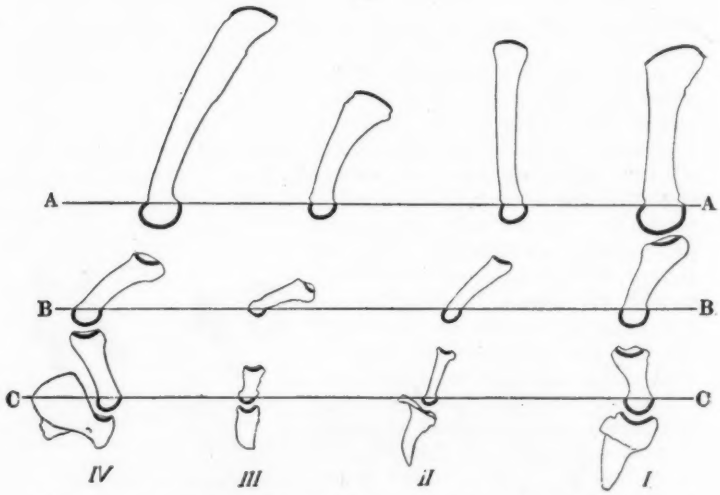

FIGURE 69—Angulation of facets in feet of (I) *Ursus*, (II) *Procyon*, (III) *Patriofelis*, (IV) *Felis*, showing increased obliquity in relation to increased angulation. A, distal facets of metacarpals; B, distal facets of first phalanx; C, distal facets of second phalanx. (Diagram after Osborn.)

tainty the gait of an animal, living or extinct, whether plantigrade, subplantigrade, or digitigrade. Professor Osborn says, p. 270: "The writer has pointed out that the angulation of the limbs in Ungulates is expressed in the angles which the proximal and distal facets make with the long axes of the shafts; *considering the shafts as perpendicular, facets in horizontal planes indicate straight limbs; facets in oblique planes indicate angulate limbs.* Exactly similar principles apply to the hand and foot of Unguiculates, as shown in Fig. 3. In the passage from *Otaria* (secondarily plantigrade), [to] *Ursus*

* Oxyæna and Patriofelis Re-studied as Terrestrial Creodonts, Bull. Amer. Mus. Nat. Hist., Dec. 1900.

(primarily plantigrade), *Procyon* (subdigitigrade), and *Felis* (digitigrade), we see that the planes of the distal facets give certain indication of the modes of progression."

In other words, by an examination of the distal ends of the metapodials, one can certainly tell whether these bones are carried in a plane parallel to the surface upon which the animal walks (plantigrade), or perpendicular to it (digitigrade), in the act of progression—a very important and valuable discovery if true. Now if there is any truth in this hypothesis, it appears to me that the character of the distal ends of the metapodials in two such typical and widely different-gaited animals as a cat and a bear would exhibit such marked and unmistakable differences in these particulars, that one would be able to tell at a glance whether the animal in question were plantigrade or digitigrade. As a matter of fact, however, and, I may add, of the most common observation and knowledge, the amount of difference in the distal articular surfaces of these bones in the cat and bear is so surprisingly small, that, in themselves, they do not give the faintest or slightest hint at such marked differences in gait. According to Professor Osborn's own showing in his diagram, the differences in the extent, arrangement, and planes of these facets, in the two animals, are very slight indeed. It should be here observed that in the diagram, if the metapodial of the bear is placed in its natural position with reference to the phalanges, the corresponding bone of the cat must be rotated to the left somewhere in the vicinity of ninety degrees, in order to represent the position which it naturally assumes in the foot of that animal. If, therefore, the planes of these facets fail to record a difference of nearly *ninety degrees of arc*, in determining the position of the bone in this case, it is pertinent to inquire how far they can be trusted in any other case. It is sufficiently obvious, I take it, that if the position of the metapodial is incapable of being fixed by this method, it is practically worthless in the further determination of the gait of the animal, since the position of these bones is the all-important factor in the case.

Let us next turn our attention to the phalanges. I quote again from the paper in question, p. 271. "As regards angulation, *Patriofelis* is shown to occupy a position intermediate between *Procyon* and *Felis*, with a decidedly *angulate* foot, the angles between phalanges 1 and 2 being especially acute. This proves that the metapodials, as well as phalanges 1 and 2, were raised off the ground by plantar and palmar pads as in *Felis*. Taking a conservative view, the feet of *Patriofelis* may be described as subdigitigrade in position. The straight terminal claws indicate that they entirely lacked the grasping and tearing power developed in *Felis*."

Using the previous examples, the cat and the bear, in the

matter of the distal facets of the first phalanges, I have taken the trouble to make careful and extensive comparisons of numerous species of these two types, and I find that the differences in the arrangement, extent, and planes, are as little marked as they are in the distal ends of the metapodials, and, in themselves, afford as little evidence of the difference in gait of the two animals. The conclusion is therefore obvious, and

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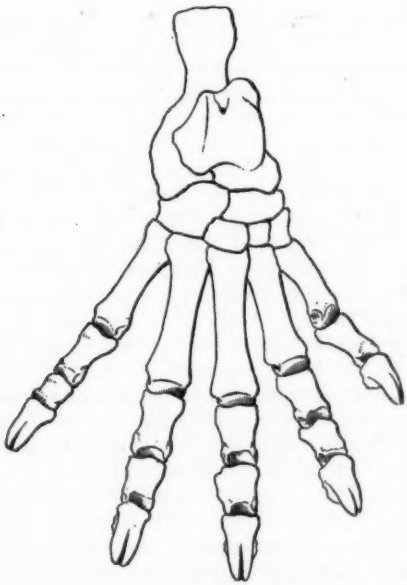


FIGURE 70.—Right hind foot of *Patriofelis ferox* Marsh; three-eighths natural size. (After Wortman.)

I think enough has been said to show that the planes of the articular facets, as applied to the feet of the Carnivora, have *little or no value* in determining whether a given animal is plantigrade or digitigrade.

Let us next direct our attention to the feet of *Patriofelis*. I find it necessary, first of all, to state that the position in which Osborn has placed the phalanges, in the diagram, instead of being less angulate than those of *Felis*, are decidedly more so. It certainly, therefore, does not occupy a position between *Procyon* and *Felis*, but a position more advanced in this particular than *Felis* itself, the fallacy of which will be evident to any anatomist at a glance. Either the diagram is wrong or the statement is incorrect, since both cannot be true.

Although there are numerous specimens of the first phalanges of *Patriofelis ferox* in the Marsh collection, after the most careful examination I fail to detect *a single example in which the distal articular surface is limited in the manner depicted by Professor Osborn in his diagram.* These specimens, moreover, agree perfectly in this respect, not only with the original figure, figure 70, of the American Museum specimen, published in my paper, but what is still more to the point, they agree with the photograph of the same specimen which Professor Osborn himself reproduces, figure 2, p. 169, of the paper under discussion. What more conclusive or final testimony is it possible to adduce in support of the contention that this diagrammatic representation of these facets is wrong and the conclusions drawn from them are entirely erroneous?

I am still of the opinion that we shall find it necessary to retain our old methods for judging the gait of these extinct animals, methods which have for their basis a consideration of the entire organization of the foot, and such as are calculated to help us as near to the truth as we shall ever be likely to come.

Among the living Carnivora the plantigrade foot is characterized by short slightly interlocking metapodials and spreading toes, whereas in the typical digitigrade foot the metapodials are more elongate, compressed, and interlocking, and the toes less spreading. In the former the naked plantar and palmar pads are enlarged and extended so as to wholly underlie these bones, while in the latter these pads are restricted to their distal ends. Judged upon the merits of this class of evidence, the feet of *Patriofelis ferox* were as plantigrade as those of the modern bears, a conclusion which, to my mind, is clearly indicated by every feature of its podial anatomy.

The third section of this paper is devoted to the so-called "Specialized Characters of the Oxyænidæ," and upon this topic I feel it necessary, if only in the interests of clearness, to make a few remarks. In the first place it is important to note that if the term "specialized" is employed in the usual or ordinary sense, common to the subject, then out of the thirty or more characters enumerated, comparatively few can be correctly called *specialized.* I have always understood this term to denote a condition the reverse of generalized, or in other words one which is uncommon, peculiar, particular, and different from others; it is also employed in the sense of advanced. The specialized characters of the Oxyænidæ should therefore be taken to indicate those which it possesses that are different from, or advanced over and above, the other families of the suborder to which it belongs. We shall presently see to what extent the characters therein enumerated are entitled to be set down as "specialized characters" of the Oxyænidæ.

I will next take up these characters *seriatim*, and make such comments as appear to me to be needful and necessary in connection with each one separately. They are as follows:

(1) "Progressive shortening of the face and elongation of cranium with reduction of teeth and development of jaw muscles;"	(1) I have explicitly and distinctly stated in my paper, p. 132, that the length of the face in *Patriofelis* is not known with certainty; it is, however, probably correct and a truly specialized character.
(2) "high sagittal crest; (3) occiput narrow;"	(2), (3) The occiput is unusually low and broad in certain species of *Limnocyon*, and the sagittal crest little developed; they do not, therefore, apply to the entire family.
(4) "a preglenoid crest;"	(4) Common to many other Creodonts and not true of two species of *Limnocyon;* unknown in *Thereutherium.*
(5) "a large postmastoid foramen;"	(5) Now known to be the stylomastoid foramen; its posterior position is also characteristic of certain members of the Mesonychidæ and is not known in any of the Limnocyoninæ, except in one species where it opens below.
(6) "no postglenoid foramina;"	(6) Stated in my paper on *Oxyæna* (Bull. Amer. Mus. Nat. Hist., 1899, p. 142) as probably present in this species; also known to be present in at least two species of *Limnocyon.*
(7) "mandibular condyles scroll-like (as in Felidæ);"	(7) Also true of many other Creodonts.
(8) "atlas with form and vertebrarterial canal as in Felidæ (Wortman);"	(8) Same character is found in other species of Creodonts, notably *Sinopa, Mesonyx,* and *Dromocyon.*
(9) "axis with elongate spine;"	(9) Unknown in *Oxyæna* and all other members of the family, but the same is true of *Mesonyx, Dromocyon,* and *Sinopa.*
(10) "certain dorsals and lumbars with progressively revolute zygapophyses (as in Mesonychidae and certain Pinnipedia, *Phoca*;"	(10) If described as having a double tongue and groove articulation, it is a truly specialized character of the family. "Revolute" is an altogether inappropriate and incorrect expression as applied to it. Neither Mesonychidæ nor *Phoca* has this character of articulation.
(11) "lumbars with progressively developed anapophyses;"	(11) Also true of other species of Creodonts, but unknown in the Limnocyoninæ.
(12) "scapula, humerus, and ulna of about equal length;"	(12) Unknown in all the Limnocyoninæ.
(13) "scapula very large, spreading superiorly (imperfectly known in *Oxyæna*), supra- and infraspinous fossæ subequal;"	(13) Scapula practically unknown in all species of the family except *Patriofelis.*

(14) "powerful acromion and metacromion processes;"	(14) Unknown in all the Limnocyoninæ.
(15) "humerus with exceptionally elongate and prominent deltoid crest, powerful supinator ridge, large entepicondyle and entepicondylar foramen;"	(15) Deltoid crest in two species of *Limnocyon* reduced; other characters common to all primitive Creodonts and carnivorous Marsupials and therefore not specialized.
(16) "olecranon process of ulna elongate, ulna grooved anteriorly;"	(16) True of nearly all Creodonta known, likewise carnivorous Marsupials; therefore primitive.
(17) "limited rotation of forearm owing to proximal expansion of radius;"	(17) Not true of *Oxyæna* nor any species of *Limnocyon* thus far known.
(18) "feet [toes] spreading;"	(18) True also of many other Creodonts; not a specialized character.
(19) "trapezium extended transversely (as in Pinnipedia, Wortman);"	(19) Not known in any species of Limnocyoninæ, but probably a distinctive and specialized character.
(20) "dorsal portion of distal metapodial facets hemispherical, ventral portion keeled (as in Fissipedia, Wortman);"	(20) True also of all Creodonta, Carnassidentia, and Carnivorous Marsupials thus far known; therefore not specialized in any sense.
(21) "digits angulate, the second phalanges strongly flexed upon first phalanges;"	(21) According to my own view this is incorrect.
(22) "subungual (retractile) processes of distal phalanges well developed (as in Pinnipedia; in Fissipedia subungual processes small, foramen vestigial, Wortman);"	(22) I prefer to believe that the introduction of the word "retractile" into my original statement is a *lapsus calami* on the part of the author, since he must surely know that a "retractile" process upon the under side of the claw is a sheer impossibility.
(23) "ilium expanded on superior (post-iliac) border into a broad lamina;"	(23) Unknown in Limnocyoninæ.
(24) "pubic symphysis not anchylosed;"	(24) Likewise true of all Creodonts and Carnassidents thus far known, and therefore generalized.
(25) "patella large;"	(25) No larger than in *Mesonyx*, *Dromocyon*, *Sinopa*, and many others.
(26) "fibula unreduced, articulating with side of astragalus but not articulating with calcaneum (progressive):"	(26) Fibula articulates with calcaneum in *Limnocyon*, but not known to do so in any other species of Creodonts.
(27) "tibia with twisted shaft and cnemial spine;"	(27) Tibia unknown in the Limnocyoninæ, but cnemial crest is present in all Creodonta known. The twisted tibia is strongly indicative of aquatic habit and is probably specialized.
(28) "tibio-astragalar facet flat, obliquely placed;"	(28) Fairly well grooved in one species of *Limnocyon*, and not very oblique. In *Patriofelis* probably specialized and indicative of an aquatic habit.

(29) "calcaneo-cuboidal facet very oblique;"	(29) Not known in all species of *Limnocyon*, but probably characteristic of the family and specialized.
(30) "large astragulo-cuboidal facets;"	(30) True of nearly all Creodonts.
(31) "external calcaneal tubercle large (as in many Creodonts and Amblypods)."	(31) Should have been stated all Creodonts known.

It will thus be seen that these characters are for the most part true only of the single genus *Patriofelis* and cannot be applied to the entire family.

I pass next to a consideration of the probable habits of *Patriofelis*, and for the sake of putting the matter clearly I quote my original conclusion, which was as follows: "From the structure of the limbs more than any other feature in the osteology of *Patriofelis*, I am led to conclude that it was aquatic or semi-aquatic in habits. The broad, flat, plantigrade feet, with their spreading toes, suggest at the first glance their use for swimming." The opposite view as stated by Osborn is as follows: "In this connection a careful restudy of all the evidence led the writer to the opposite conclusion, that these were powerful *terrestrial, or partly arboreal, animals, analogous to the Cats in habits of feeding*, with analogous (not homologous) sectorials, clumsy in limb structure, without prehensile claws, and presenting no evidence of successors among the modern Carnivora."

As regards the view that these animals were arboreal or partly so, I have little comment to make; it is to my mind, however, so extremely improbable, if not impossible, that I hesitate to give it serious consideration. Its fallacy, it seems to me, is clearly evident when it is remembered that among the living Carnivora the habitual climbers are almost without exception light, agile, sharp-clawed species, capable of sufficiently swift movement to capture arboreal prey. A heavy, clumsy, blunt-clawed type like *Patriofelis* would be as much out of place in the trees as could well be imagined. We thus limit the question either to an aquatic manner of life or a terrestrial one or both, since there is no evidence that the animal had fossorial habits.

Any conclusion we may reach must take into consideration and accommodate itself to the following facts: (1) That whatever constituted the chief food supply of the animal was of such a nature as to cause unusual wear of the teeth, since in almost every known specimen that had reached maturity, the teeth are much worn; (2) that the animal was strictly carnivorous; (3) that its prey, whatever it may have been, was evidently not swift and active, otherwise it could have easily escaped so awkward and clumsy a creature; (4) that the manner of cap-

turing its prey and its habits of feeding were not analogous nor similar to those of the cats, since the evidence positively forbids the idea of any prehensile powers of the claws, one of the most preëminently distinguishing features of the Felidæ in this respect; and (5) that it was likewise not similar to that of the dogs, for the structure of the limbs disproves the suggestion of a runner.

What osteological character or characters do the living aquatic Carnivora possess, by means of which their habits could be detected if known from their skeletons alone? The various degrees of modification for a swimming habit are progressively shown by such types as the mink, otter, sea-otter, sea-lion, and seal. The mink and otter are semi-aquatic, the sea-otter more aquatic, and the sea-lion and seal almost exclusively so. The limbs, and especially the feet, exhibit the greatest amount of modification of any parts of the skeleton and the degree of this modification is proportioned to the extent of the aquatic habit. In cases of extreme specialization, as in the sea-lion and seal, the fore and hind feet are almost equally modified, but in such an example as the sea-otter, it is only the hind feet that show any considerable adaptive changes of this character. This is also true of the mink and otter, but in these types the difference between the fore and hind feet is not so great.

It is for this reason that I limit what I shall have to say to a consideration of the posterior limbs; and it should be noted that all these aquatic or semi-aquatic species are plantigrade in gait when upon land, that the metatarsals are short and little interlocking, and that the toes are spreading. Taking the foot of the sea-lion as an extreme type, it will be seen that when placed with the plantar surface upon the ground, in the direction of the long axis of the body, the articular surface for the tibia looks upwards and very much inwards, so that if the tibia is articulated it does not occupy a vertical position as in the terrestrial species, but leans very much inwards towards the median line. If made to assume a vertical position the plantar surface of the foot is turned strongly inwards. At the same time the tibia is twisted in such a way that the fore and aft planes of the articular faces of the two ends do not coincide. These characters in connection with the elongation of the phalanges constitute the chief peculiarities of the hind limbs of the aquatic Carnivora, and, as far as known, are present in all of them. With the exception of the elongation of the phalanges, *Patriofelis* exhibits these identical characteristics of the hind limbs, and if they have any significance at all, *they indicate an aquatic or partially aquatic habit of the species.* I have yet to discover any evidence which opposes itself to the correctness of this view.

I have suggested that the animal preyed upon the numerous

species of turtles that inhabited the Bridger lake, and this is rendered all the more probable by the presence in these deposits of coprolites of some large carnivorous Mammal, which contain fragments of turtle shell. While it is not known with certainty to what species these coprolites pertain, it is, I think, in connection with the probable aquatic habits of the species, a fair presumption that they refer to *Patriofelis*. The great wear of the teeth as well as the power of the jaws accord well, moreover, with the view that they were used for crushing the strong bony coverings of the turtles, which may be said to have literally swarmed in the tropical or semi-tropical waters of the ancient lake or river as the case may be. The suggestion of Osborn that the specialization of the teeth and the increase in the size of the jaws are reasons for disbelieving in its aquatic habits has little force. An exactly parallel case is seen in *Potamotherium* and *Lutra* (ancestor and descendant), in which the same thing has occurred. The teeth have been reduced in number, enlarged and specialized, and the jaws shortened and increased in size, notwithstanding *Lutra* is to-day preëminently a fish eater.

Touching their relationship to the Pinnipedia I have no new facts to add. I have not asserted that the seals have been derived from any known species of *Patriofelis*, but that they *may have* been derived from some as yet undiscovered member of this group, and the reasons for such a belief, which have already been fully stated, have not, to my mind, been in any way affected by this restudy of the subject on the part of Professor Osborn.

Subfamily Limnocyoninæ.

As already remarked, this group appears for the first time in the Bridger and continues into the Uinta. According to our present understanding, the three or four American species appear to be best classified in the single genus *Limnocyon*, although it is not altogether improbable that two of them, when more fully known, will require to be placed in separate genera. The European representative of this subfamily, *Thereutherium*, is distinct and shows a considerable advance over the American species in the matter of tooth specialization. The two genera may be distinguished as follows:

First premolar above and below two-rooted; last superior molar transverse, relatively large, with three well-developed roots and external and internal cusps; inferior molars with moderate-sized basin-shaped heels and internal cusps. *Limnocyon.*

First superior premolar above and below single-rooted; last superior molar much reduced, vestigial; heels of inferior molars reduced, and internal cusps vestigial or absent. *Thereutherium.*

[To be continued.]

Art. X. — *On a Miniature Anemometer for Stationary Sound Waves;* by Bergen Davis, Ph.D.

The anemometer which is in such general use for measuring wind velocities possesses the convenient property of rotating in the same direction irrespective of the direction of the air currents acting upon it.

In a stationary sound wave we have the condition of an alternating current or impulse of air, the direction of whose motion is twice reversed during each complete vibration. Such alternating currents of air, if of sufficient magnitude, should act upon an anemometer in the same manner as a continuous current, provided the cups of the anemometer are sufficiently small. The writer has constructed a number of miniature anemometers which have been found to rotate with considerable velocity in a stationary sound wave. The rate of rotation varied with the position of the anemometer along the wave. It was a maximum at the middle of the loop, and the rotation ceased entirely at the nodes.

An investigation of this effect was undertaken for the purpose of determining the relation between the amplitude of vibration and the rate of rotation, and also the influence of the size of the anemometer cups.

The stationary wave used was that produced in a stopped organ-pipe speaking its first overtone. Two nodes were thus obtained, one at the stopped end and the other a short distance from the mouth. A thin rubber diaphragm was placed across the pipe at the node nearest the mouth for the purpose of protecting the interior of the pipe from disturbances that might arise from blowing. The portion of the pipe between the diaphragm and the stopped end contained one-half of the stationary wave. The side of the pipe from the diaphragm to the stopped end was removed and a glass panel substituted for it, thus rendering the interior of the pipe visible. The pipe was 68^{cm} long from lip to stop, and $5{\cdot}3$ by $6{\cdot}4^{cm}$ in cross-section. The diaphragm was placed 16^{cm} from the lip, as this was found to be the position of the first node. The half wave between the diaphragm and the stop was 52^{cm} long. A centimeter scale was placed along the pipe with the zero at the stopped end for the purpose of measuring distances along the wave.

The cups of the anemometers were made from gelatine capsules such as are used for medical purposes. These capsules were divided longitudinally, each part so obtained forming a

hollow half-cylinder. The half-cylinder cups were mounted on the ends of four cardboard arms, in the center of which was a glass pivot by which the whole arrangement was supported on the point of a fine needle. Three anemometers were constructed bearing cups of three sizes. These anemometers will be referred to in this paper by the trade numbers of the capsules from which they were made.

Anemometer No. 00 carried four cups, each of which was ·75^{cm} in diameter and 2^{cm} long.

Anemometer No. 2 carried eight cups, two on each arm, each of which was ·58^{cm} in diameter and 1·4^{cm} long.

Anemometer No. 5 carried eight cups, two on each arm, each of which was ·45^{cm} in diameter and ·8^{cm} long.

In conducting the experiments a stroboscopic disc was used to count the revolutions of the anemometers; also a mercury manometer was employed to obtain the same pressure of blowing the pipe throughout the experiments.

The mean results of a number of experiments are given in the tables below:

Anemometer No. 00.

Position in pipe.	Rate of rotation.
0	0
5	1·45
10	5·71
15	9·09
20	10·
25	10·9
30	10·34
35	9·95
40	7·79
45	3·80
52	0

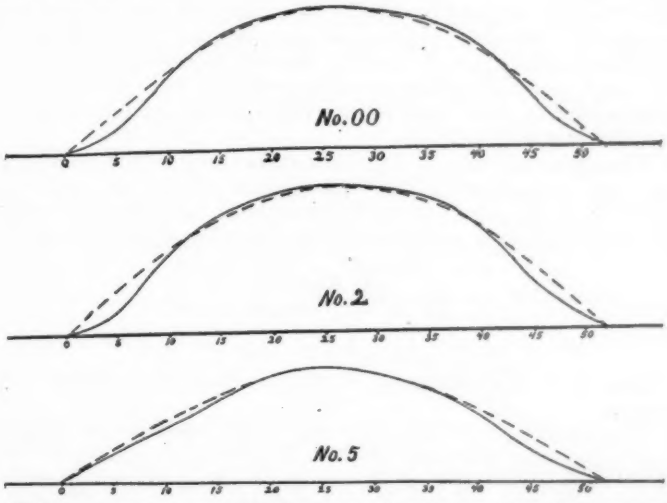
Anemometer No. 2.

Position in pipe.	Rate of rotation.
0	0
5	1·66
10	6·46
15	9·21
20	10·55
25	11·3
30	10·8
35	10·25
40	7·52
45	3·1
52	0

Anemometer No. 5.

Position in pipe.	Rate of rotation.
0	0
5	1·27
10	4·28
15	6·07
20	8·51
25	8·7
30	8·16
35	7·38
40	5·17
45	2·26
52	0

These tables are plotted in the figures below. The abscissæ are distances along the wave and the ordinates are rates of rotation per second. The full lines are the observed curves and the broken lines are sine curves.



These curves correspond quite closely to the sine curves near the middle of the loop, where the amplitudes of vibration have considerable magnitude; hence one may infer that the rate of rotation is proportional to the amplitude when such amplitude is sufficiently great. The depressions in the curves near the nodes indicate that the anemometers are not so strongly affected when the amplitudes are small in comparison to the radii of the cups. The rate of rotation is nearly the same for both the No. 00 and the No. 2 anemometers, from which one concludes that there is a definite relation between

the linear velocity of the cups and the average velocity of the vibrating air. The No. 5 anemometer rotates with a somewhat less velocity in all parts of the wave. This may arise from the fact that, owing to the small size of the cups, the forces acting are very small, and hence the friction of the pivot may have an appreciable effect, as this friction factor is proportionately much larger than in the case of the other anemometers.

If we could measure either the average velocity of the maximum velocity of the vibrating air at the middle of the loop, one could easily calculate the amplitude of vibration. Since the air is executing a harmonic motion, the velocity of the cups will not bear a simple relation to the average velocity of the air, as the motion of the air, near the instant of reversal, will be slower than that of the cups and have a retarding effect even though it be in the same direction. The greater part of the impulse will be delivered to the anemometer at the time when the air is at the middle of its swing and the velocity is a maximum. For the purpose of approximate measurement I have assumed a ratio of 1 to 2·7 between the linear velocity of the cups and the maximum velocity of the air. This ratio is approximately that applied to the ordinary anemometer in measuring wind velocities.

The linear velocity of the anemometer cups at the middle of the loop was about $117{\cdot}4^{cm}$ per second, hence the maximum velocity of the air was 317^{cm} per second. In order to obtain the amplitude it is convenient to know the average velocity V.

$$V = \frac{\int A \sin pt\, dt}{\int dt}$$

where A is the maximum velocity. Hence $V = 202^{cm}$ per second.

The frequency of the pipe was 338 vibrations per second, hence the amplitude was $2{\cdot}99^{mm}$. The term amplitude is here used to denote the total excursion of an air particle during a half period.

This value for the amplitude is somewhat greater than a corresponding value obtained by means of a new effect which was soon afterwards applied by the writer to the same problem.*

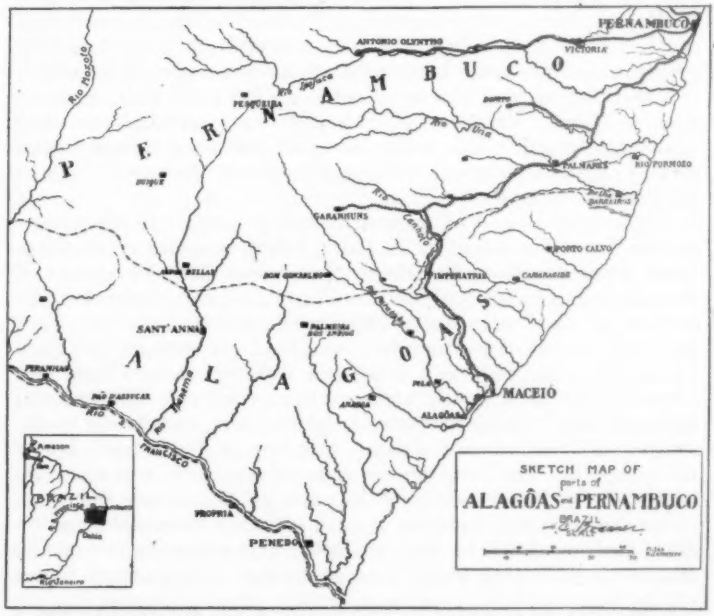
The experiments above described were performed at the Physical Laboratories of Columbia University two years ago, but the pressure of other affairs has delayed their publication to the present time.

Göttingen, Oct. 5, 1901.

*This Journal, September, 1900, also Physical Review, July, 1901.

ART. XI. — *The Occurrence of Fossil Remains of Mammals in the Interior of the States of Pernambuco and Alagôas, Brazil;* by JOHN C. BRANNER. With Plate I.

THE following observations, upon a region whose geology is but little known, were made on a trip from Pão d'Assucar in the State of Alagôas on the lower course of the Rio São Francisco to Aguas Bellas in the State of Pernambuco. It has long been hoped that these observations might be extended in the field, and that a study might be made of the collections of Pleistocene mammalian remains in the Museu Nacional at Rio de Janeiro, but it now seems improbable that either will shortly be done. This fragment is, therefore, published in the hope that it may be of service in directing attention to and arousing interest in the subject.



The Rio São Francisco between the falls of Paulo Affonso and Pão d'Assucar runs through a narrow channel cut in a plain of crystalline rocks—schists, gneisses and granites. The plain is a hilly one rising to an average height of fifty and sixty meters above the river, apparently an ancient baselevel. Upstream the plain extends to and beyond Piranhas, the head of navigation on the lower river. The accompanying illustra-

tion (Plate I) shows well the character of the river channel and of the topography between Pão d'Assucar and Piranhas.

The rocks of the region in the vicinity of Pão d'Assucar are all crystalline and are probably of Archean age. The sharp peak on the river near the town and from which it receives its name has the appearance of being made of stratified rocks standing on end. On the south side of the river is a series of similar hills following the strike of the beds. The rocks, however, are not sedimentary beds but dark mica schists alternating with reddish porphyritic gneiss. The beds (or the schistosity) strike southeast—northwest. Two or three kilometers up the river there are massive granites exposed on the river banks.

The road from Pão d'Assucar to Aguas Bellas passes through the villages of Meirús or Campo Alegre (three leagues from Pão d'Assucar) and Sant' Anna. The country from the Rio São Francisco at Pão d'Assucar to Aguas Bellas, in the State of Pernambuco, and thence to Pedra Pintada, ten leagues northeast of Aguas Bellas, is all of crystalline rocks—mostly granites, gneisses and schists, with a few occurrences of marble.*

Over the surface of these rocks are here and there patches of a thin layer of water-worn materials of various sizes and mostly of quartz. The worn materials are not confined to the stream channels or to the valleys, but spread alike over high as well as low ground.

Eight leagues east of Aguas Bellas, at a cattle ranch known as the Lagoa da Lagea (Flat-Rock Lake), a quantity of large fossil bones were found about the year 1873. The rocks of the immediate neighborhood are all granites and gneisses. The surface of the rocks have weathered unevenly, and in places the soil is thin or altogether wanting. In one of the rock basins thus formed, soil, loam and water-worn bowlders had accumulated to a depth of more than a meter. An artificial reservoir was made by excavating the soil, and it was in the digging of this reservoir that a quantity of large fossil bones were found. The pool at the time of my visit was about 30 meters long by about 20 wide, and a little more than one meter deep. As nearly as I could estimate from information furnished by the man who made the excavation and from the fragments still lying about the place, more than a ton of bones

* The occurrence of marble in this region of granites, gneisses and schists is worthy of note. One of the exposures is at Ribeiro de Baixo, two or three leagues south of Aguas Bellas and west of the road leading to Sant' Anna. The marble is white, both fine and coarse-grained, and is used for making lime. Another locality is between the Dois Riachos and Serra do Menino in the Calderão do Chão, about five leagues from Aguas Bellas. Another is on the Fazenda dos Meninos, about three leagues from Aguas Bellas at a place called Serrote de Cal (limestone ridge).

and teeth were taken from this reservoir. The best preserved and most striking specimens had already been carried away by neighbors and visitors, and some of them were said to have been sent to Bahia by the owner of the property, but to whom or to what institution they went I was unable to learn. Many vertebræ and large fragments of bone had been used along with stones to build a wall around the basin, while smaller pieces had been left exposed in heaps. From these heaps I gathered fragments enough to load three horses, and this much was sent to the collections of the Commissão Geologica at Rio de Janeiro. Upon the suspension of the work of the Commission shortly afterwards this material was turned over to the Museu Nacional in Rio de Janeiro, where it is probably still preserved. Among the specimens brought away were two pieces of tusks, several vertebræ and several broken teeth of the mastodon, the jaw and teeth of some other kind of large mammal, and pieces of bones and teeth of still other animals. Many but not all of these bones were more or less worn as if they had been trampled under foot by large animals. That this wearing was done before they were excavated is shown by the fact that in some instances the worn and broken bones were found cemented in sand and gravel, and remain as hard solid masses even after years of exposure to the weather.

Among the materials taken from the excavation was a rude unpolished stone pestle made of the fine-grained granite of the neighborhood, about 18 centimeters long, and nine or ten centimeters in diameter. It is impossible to say whether this pestle or hammer was mingled with the bones or came from the soil above them. The man who did the digging had no recollection of its location further than that it was taken out with the bones and other materials from the excavation.

I could only spend a couple of days in examining this locality. It was hoped that some digging might be done in search of additional material, but the difficulty of arranging laborers and the delay caused by lack of anything like proper tools made exploration impossible at that time. The original reservoir was made by scraping the earth with a hoe upon a dry hide and this was then drawn away by half-wild bullocks.

The occurrence of the fossil bones of large mammals at Lagoa da Lagea in the State of Pernambuco is a typical one for northeastern Brazil. Many cases have been reported of the finding of these fossils under similar circumstances in the States of Alagôas, Pernambuco, Parahyba, Rio Grande do Norte and Ceará, and it seems probable that they may be found throughout the entire area of Brazil that is subject to drouths. About three leagues from the Lagoa da Lagea on

the road leading to Pedra Pintada is a place known as Lageiro, where an excavation was made in the rock basin very similar to that already described and for similar purposes. Here again I found many fragments of bones of mastodons and of other mammals, some of them of enormous size, and others smaller than those of the mastodon.

On the road leading from Lagoa da Lagea to Aguas Bellas at a place known as Lagoa Cavada is another excavation from which it is said many fossil bones were taken. An examination of the soil thrown out at this place failed to disclose any such fossils however.

Large fossil bones were reported to me to have been found at Meirús, a small town three leagues northeast of Pão d'Assucar. I did not see either the excavation or the fossils at this place, but I learned from several intelligent gentlemen that while excavations were being made several years before for making a watering pond for cattle, bones many times as large as those of an ox were found in the soil. It was reported that when this fact became known the government sent persons to preserve these fossils and that the best of them were sent away—where I was unable to learn.

In every instance that came to my attention the fossils have been taken from what were originally ponds, pools or marshes of fresh water that have subsequently silted up and have been discovered in the digging of artificial reservoirs.

The region in which these large fossils occur so abundantly is one now subject to prolonged drouths, and I am disposed to think that the circumstances under which these bones occur suggest, at least, that the animals died of thirst. To any one visiting the drouth regions of Brazil between August and January this explanation seems to be a very natural one. The whole country is parched save the narrow strips of gradually disappearing green along the water courses. The country is but thinly populated and the chief industry is cattle-raising. Beyond these green belts one may travel for many a league without finding a sign of water. When, as often happens, the dry season is prolonged beyond its normal length, the suffering of the cattle is extreme. They are obliged to eat the pulp of the cacti that grow throughout this region, and the herdsmen obtain water for them by digging holes in the sand of the dry river beds. In long drouths, especially when they last for an entire year or even for several years, this source of water supply fails and the cattle must either be driven toward the coast, where water may be had, or they must be left to perish. Under the protection of man cattle may now survive the longest drouths, but left to themselves it is doubtful whether they

The channel of the Rio São Francisco seen from the sugar loaf hill at Pão d'Assucar, State of Alagôas; looking up stream.

could withstand the long drouths that occasionally occur in the interior of northeast Brazil. I was led to this conclusion when I first visited the interior of Alagôas and Pernambuco in 1876. I quote from Dr. J. W. Gregory's "Great Rift Valley" what seems to be corroborative evidence that in Africa large animals do perish as I have suggested:* "Here and there around a water-hole we found acres of ground white with the bones of rhinoceros and zebra, gazelle and antelope, jackal and hyena, and among them we once observed the remains of a lion. All the bones of the skeletons were there, and they were fresh and ungnawed. The explanation is simple. The year before there had been a drouth which had cleared both game and people from the district. Those which did not migrate crowded around the dwindling pools, and fought for the last drop of water. These accumulations of bones were due, therefore, to a drouth and not to a deluge."

It is much to be desired that the fossil Pleistocene mammals of Brazil be studied systematically. The work of Lund upon the cave fauna of Brazil is classic, but no attempt has yet been made to get together the material from the ancient watering places of northeast Brazil, while the fragmentary collections in the Museu Nacional and in the hands of the other scientific organizations and of private individuals are undescribed and unknown. The only publication that has been made upon the subject is a paper by Dr. F. L. C. Burlamaqui published at Rio de Janeiro in 1855 by the Sociedade Vellosiana entitled "Noticia acerca dos animaes de raças extinctas descobertos em varios postos do Brasil."

Stanford University, California, December 10, 1901.

* The Great Rift Valley, by J. W. Gregory, London, 1896, pp. 268–269.

ART. XII.—*The Estimation of Copper as Cuprous Sulphocyanide in the Presence of Bismuth, Antimony, Tin and Arsenic;* by R. G. VAN NAME.

[Contributions from the Kent Chemical Laboratory of Yale University,—CVI.]

IT has long been known that copper may be quantitatively separated from a number of other metals by precipitation as cuprous sulphocyanide. The additional fact that this salt is suitable for direct weighing as a means of estimating copper was mentioned, apparently for the first time by Rivot* in 1854, and was confirmed a quarter of a century later by the experiments of Busse,† who employed the process for determining copper not only alone but also in the presence of iron, nickel, zinc and arsenic. Recent work by the present writer‡ has shown that, with the sole modification of filtering and weighing upon asbestos, Rivot's method is accurate and satisfactory.

In view of the tendency of bismuth, antimony and tin to form insoluble basic chlorides in solutions containing only a slight excess of hydrochloric acid, and the difficulty of obtaining a complete precipitation of cuprous sulphocyanide in strongly acid solutions, the estimation of copper by the above method in the presence of these metals seemed to present some difficulties. The following investigation, in which arsenic was also included on account of its close relationship with the above metals, was accordingly undertaken.

The first series of experiments yielded the results given in Table I, the method being as follows: A convenient quantity of a copper sulphate solution of about $\frac{1}{5}$ normal strength was measured from a burette, diluted, and acidified with a definite amount of hydrochloric or sulphuric acid. If tartaric acid was employed it was added at this point, after which the solution of arsenic, bismuth or antimony was introduced and the copper finally precipitated by ammonium bisulphite and ammonium sulphocyanide. Of the last a uniform amount, 70^{cm^3} of a decinormal solution, was used for each experiment. The ammonium bisulphite solution was prepared in the usual way by passing sulphur dioxide into strong ammonia.

Arsenic was introduced in the form of measured portions of a standard arsenious acid solution which were made faintly acid to litmus just before addition. Bismuth and antimony were taken in the form of solutions of the chlorides in dilute hydrochloric acid, the amount of acid thus introduced into the determination being in all cases taken into account.

* Compt. Rend., xxxviii, 868. † Zeitschr. anal. Chem., xvii, 53.
‡ This Journal, vol. x, 451.

All the determinations were allowed to stand fifteen hours or more before filtering to insure completeness of precipitation. The filtering was performed upon asbestos in a perforated crucible, the precipitate thoroughly washed with cold water, dried at 105° to a constant weight, and weighed as cuprous sulphocyanide.

TABLE I.

Final volume 500$^{cm^3}$.

70$^{cm^3}$ of approximately decinormal NH_4SCN used for each experiment.

	Cu taken grm.	As taken as H_3O_3As grm.	H_2SO_4 cm^3.	Tartaric acid. grm.	HNH_4SO_3 sat. sol. cm^3.	$Cu_2S_2(CN)_2$ found. grm.	Calculated as Cu. grm.	Error. grm.
1.	·3144	0·2	5		5	·5889	·3078	—·0066
2.	"	0·2	"		10	·5978	·3124	—·0020
3.	"	0·05	"		10	·5919	·3091	—·0053
4.	"	0·2	"		15	·6020	·3146	+·0002
			HCl sp. gr. about 1·17 cm^3.					
5.	"	0·4	15		10	·5969	·3120	—·0024
6.	"	0·05	"		"	·5995	·3133	—·0011
7.	"	0·6	10	1	"	·6035	·3154	+·0010
8.	"	0·5	"	1	"	·6032	·3153	+·0009
9.	"	0·4	"		"	·6015	·3144	·0000
10.	"	0·2	"		"	·6024	·3148	+·0004
11.	"	0·1	"		"	·6017	·3145	+·0001
12.	"	0·1	9	1	"	·6029	·3151	+·0007
13.	"	0·01	10		"	·6022	·3147	+·0003

The negative errors of experiments 1 to 3 of Table I are plainly due to the large amount of acid present, for they disappear when the bisulphite is sufficiently increased (experiment 4), and the deficiencies in nos. 5 and 6 may be ascribed to the same cause, for they are not found in the subsequent experiments with arsenic where less acid was used. Tartaric acid was added in three of the above determinations, but its use in separations from arsenic is obviously unnecessary.

From these results it is evident that the estimation of copper in the presence of arsenic by this method is entirely practicable in either sulphuric or hydrochloric acid solution.

When bismuth is present a much closer adjustment of conditions is necessary. Experiments 14 to 19 show the effect of attempting to keep the bismuth in solution with hydrochloric

TABLE I (continued).

	Cu taken. grm.	Bi taken as $BiCl_3 + HCl$. grm.	HCl cm^3.	Tartaric acid. grm.	HNH_4SO_3 sat. sol. cm^3.	$Cu_2S_2(CN)_2$ found. grm.	Calculated as Cu. grm.	Error. grm.
				Final volume 500^{cm3}.				
14.	·3144	0·5	20		10	·6534	·3415	+·0271
15.	"	0·4	25		"	·5933	·3101	—·0043
16.	"	0·2	20		5	·5932	·3101	—·0043
17.	"	0·2	"		10	·6014	·3143	—·0001
18.	"	0·1	"		"	·5977	·3124	—·0020
19.	"	0·05	"		"	·5998	·3135	—·0009
				Final volume 300^{cm3}.				
20.	"	0·5	10	1	5	·6007	·3139	—·0005
21.	"	0·4	"	"	"	·6018	·3145	+·0001
22.	"	0·2	"	"	"	·6003	·3137	—·0007
23.	"	0·1	7	"	"	·6033	·3153	+·0009
24.	·3163	0·1	10	"	"	·6033	·3153	—·0010
25.	"	0·1	8	"	"	·6056	·3165	+·0002

acid, using no tartaric acid. In experiment 14 the free acid present during the precipitation of the copper did not suffice to hold up all the bismuth. In the others, with the exception of no. 17, the acid prevented the complete precipitation of the copper.

For experiments 20 to 25 the quantities of hydrochloric acid required were materially diminished by the addition of tartaric acid, and by reducing the total volume from 500^{cm3} to 300^{cm3}. The quantities of tartaric and hydrochloric acids required were previously determined by a series of blank tests and both kept as low as possible.

The results fall fairly near the theory but average a trifle low, and the filtrates of all, even those which show positive errors, gave decided tests for copper when concentrated and treated with potassium ferrocyanide. Moreover, a slight variation in the conditions would allow some of the bismuth to be precipitated. The results therefore are hardly satisfactory.

TABLE I (continued).

	Cu taken. grm.	Sb taken as $SbCl_3 + HCl$. grm.	HCl. cm^3.	Tartaric acid. grm.	HNH_4SO_3 sat. sol. cm^3.	$Cu_2S_2(CN)_2$ found. grm.	Calculated as Cu. grm.	Error. grm.
				Final volume 500^{cm3}.				
26.	·3163	0·5	10	2	5	·6024	·3148	—·0015
27.	"	0·4	8	"	"	·6043	·3158	—·0005
28.	"	0·3	"	"	"	·6044	·3159	—·0004
29.	"	0·5	5	"	"	·6046	·3160	—·0003
30.	"	0·4	"	"	"	·6054	·3164	+·0001
31.	"	0·2	"	"	"	·6058	·3166	+·0003

Antimony is affected to a much greater extent than bismuth by the presence of the tartaric acid, so that if enough of the latter is present, relatively little hydrochloric acid is required to hold the antimony in solution. As the amount of the tartaric acid is practically without effect upon the precipitation of the copper, these conditions are favorable for the process. Experiments 26 to 31 give the results obtained in the presence of antimony, which show that the process is practicable.

In all the experiments thus far described the excess of ammonium sulphocyanide above the amount theoretically required has been comparatively small, 70^{cm^3} of the decinormal solution having been employed where the theory called for about 50^{cm^3}. It has been elsewhere shown* that increase in the amount of the sulphocyanide diminishes the effect of the hydrochloric acid present. This fact has an important application in the separation of copper from bismuth, because it is possible, even when the solution contains an excess of hydrochloric and tartaric acid above the amount required to keep the bismuth in solution, to precipitate the copper completely by employing a sufficient quantity of ammonium sulphocyanide. By working in this way in solutions more strongly acid than would otherwise be consistent with accuracy, an additional advantage is gained because the consequent retardation of the precipitation produces precipitates which can be more easily filtered than those obtained from neutral or less acid solutions.

For the experiments of Table II the precipitation was carried out in the manner just described, and as the quantity of copper employed in the previous determinations had proved rather too large to be conveniently filtered and washed in a crucible of the ordinary size, a smaller amount was taken. A new copper sulphate solution of about $\frac{1}{20}$ normal strength was employed, the other solutions being the same previously used.

The results obtained with bismuth are given in experiments 1 to 8. For this amount of copper the theory requires about $12{\cdot}5^{cm^3}$ of the decinormal ammonium sulphocyanide, but owing to the amount of acid present the results are low until about 125^{cm^3} are added, beyond which point further increase produces no effect. Carried out in this way the separation from bismuth is satisfactory and the results accurate.

Tin in the higher condition of oxidation may be successfully treated in the same manner as experiments 9 to 11 show. Tartaric acid is of material assistance in reducing the amount of hydrochloric acid necessary to hold the tin in solution, whether in the stannic or stannous state.

The estimation of copper in the presence of tin in the

* This Journal, vol. xiii, p. 23.

TABLE II.

Final volume 200$^{cm^3}$.

	Cu taken. grm.	Bi. grm.	HCl sp. gr. about 1·17. cm^3.	Tartaric acid. grm.	HNH_4SO_3 sat. sol. cm^3.	NH_4SCN approx. $n/10$. cm^3.	$Cu_2S_2(CN)_2$ found. grm.	Calculated as Cu. grm.	Error. grm.
1.	·0793	0·2	6	1	2	15	·1329	·0695	—·0098
2.	"	0·2	"	"	"	35	·1479	·0773	—·0020
3.	"	0·2	"	"	"	60	·1504	·0786	—·0007
4.	"	0·1	"	"	"	100	·1512	·0790	—·0003
5.	"	0·3	"	"	"	125	·1515	·0792	—·0001
6.	"	0·2	"	"	"	"	·1518	·0793	·0000
7.	"	0·2	"	"	"	"	·1519	·0794	+·0001
8.*	"	0·2	"	"	"	230	·1519	·0794	+·0001
		Sn taken as $SnCl_4$ + HCl. grm.							
9.	"	0·2	5	"	"	40	·1502	·0785	—·0008
10.	"	0·2	6	"	"	125	·1514	·0791	—·0002
11.	"	0·2	5	"	"	130	·1516	·0792	—·0001
		taken as $SnCl_2$ + HCl. grm.							
12.	"	0·2	6	"	"	125	·1529	·0799	+·0006
		As. grm.							
13.	"	0·2	"	"	"	"	·1523	·0796	+·0003
		Sb. grm.							
14.	"	0·2	"	2	"	"	·1518	·0793	·0000
		As, Bi, Sb, Sn of each grm.							
15.	·0795	0·1	"	"	"	130	·1523	·0796	+·0001
16.	"	0·1	"	"	"	"	·1525	·0797	+·0002

stannous condition requires some care, because the bisulphite is often acted upon by a solution of stannous chloride, and a slight precipitate of sulphur thrown down from a mixture of these solutions upon standing. Unless, however, the amount of tin present is more than equivalent to the copper, it may be readily oxidized to the stannic state by merely adding the sulphocyanide before the bisulphite. The tin then acts as the reducing agent and a corresponding amount of copper is thrown down, after which bisulphite may safely be added and the rest

* Final volume 300$^{cm^3}$.

of the copper precipitated. Determination 12 of the table was treated in this way, but as the tin present was much more than equivalent to the copper, some precipitation of sulphur probably took place, as the high result would indicate. In all such cases it would be better to convert the tin into the higher condition by some suitable oxidizing agent before precipitating the copper. Where the weight of copper present is not desired, but merely a separation between the copper and tin, this precaution is of course unnecessary.

Experiments 13 and 14, with arsenic and antimony respectively, show that for these metals the conditions which gave good results with bismuth and tin are equally favorable.

In experiments 15 and 16 arsenic, bismuth, antimony and tin were all present to the extent of 0·1 grm. of each metal, and the results for copper are still accurate.

If cuprous sulphocyanide is precipitated in the presence of a moderate amount of free acid, using a decided excess of ammonium sulphocyanide, as was done in the experiments of Table II, the tendency of the precipitate to pass through the filter during the washing may be almost completely overcome. It is, however, more likely to appear the more rapidly the precipitation has taken place, that is, the smaller the effective amount of acid present. This tendency, in the experience of the writer, need not greatly interfere with the accuracy of the determination. If only a light pressure of the filter pump is used, the washing may generally be completed and the small quantity of copper thus lost disregarded. A very distinct cloudiness in the filtrate may be caused by an amount of copper not greater than one or two tenths of a milligram, and the loss from this cause will seldom exceed this limit. Although, on the other hand, by precipitating in strongly acid solutions cuprous sulphocyanide can be thrown down in a form that filters well, the losses from incomplete precipitation may be many times greater.

The filtrates from determinations 15 and 16, the first of which showed a distinct cloudiness, were treated with great care for the recovery and estimation of the trace of copper present. The colorimetric method described in a previous article* was used in determining the copper, and the amounts found were respectively 0·00034 and 0·00020 grm., these figures representing the sum of the mechanical loss with that due to the solubility of the precipitate in the acid solution.

Under the conditions of Table II, the estimation of copper in the presence of arsenic, bismuth, antimony and tin, either separately or in any combination, is obviously possible. To

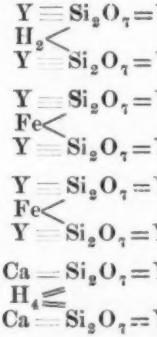
* This Journal, vol. xiii, 22.

separate copper from unknown quantities of bismuth, or from mixtures containing bismuth, the procedure would be as follows: Having the copper and bismuth in hydrochloric acid solution, add tartaric acid and, after diluting if necessary, determine by blank tests with small aliquot portions of the solution how much ammonium bisulphite can be added to the whole without precipitating the bismuth. Then keeping the bisulphite well within this limit, carry out the precipitation of the copper as already described, using a considerable excess of ammonium sulphocyanide. Where bismuth is absent, antimony and tin could be treated in the same way, but the latitude possible in the adjustment of the conditions is so much greater with these metals that preliminary tests would usually not be needed. For the separation from arsenic no precautions are required beyond a reasonable degree of acidity of the solution.

The writer is under obligation to Prof. F. A. Gooch for his kind advice and helpful suggestions.

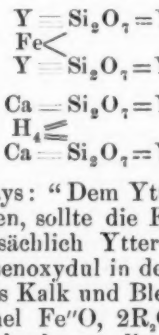
ART. XIII.—*The Composition of Yttrialite with a Criticism of the formula assigned to Thalénite;* by W. F. HILLEBRAND.

IN a paper describing the new yttrium silicate thalénite,* the author, C. Benedicks, casts doubt on the formula assigned by Hidden and Mackintosh† to their mineral yttrialite from Llano Co., Texas, for which they deduced the formula R_2O_3 $2SiO_2$ or $R_2Si_2O_7$, in which R_2O_3 includes the sesquioxid equivalents of very considerable percentages of monoxides and dioxides. Benedicks would assign yttrialite to a group of which rowlandite is the prototype and to which he believes thalénite and kainosite belong, being either plain basic salts of $H_6Si_2O_7$ of the type $R''R'''_4Si_4O_{15}$ or derivatives in which the fifteenth oxygen atom is replaced by its equivalent in fluorine (rowlandite) or CO_3 (kainosite), as shown below.



Thalénite.

Yttrialite.



Rowlandite.

Kainosite.

Benedicks says: "Dem Yttrialit, von Hidden and Mackintosh beschrieben, sollte die Formel R_2O_3, $2SiO_2$ zukommen, worin R hauptsächlich Ytter-und Thorerde ist. Dabei wird aber ca. 4% Eisenoxydul in der Analyse vernachlässigt. Wird dies nebst etwas Kalk und Bleioxyd mitgerechnet, so bekommt man die Formel $Fe''O$, $2R_2O_3$, $4SiO_2$, analog mit der des Thalénits, welche besser die Zusammensetzung des Yttrialits wiedergibt, obgleich die Ubereinstimmung gar nicht gut ist."

It is, however, not true that Hidden and Mackintosh neglected to take account of the ferrous iron, etc., of their analysis. It was regarded in the derivation of their empirical formula $R_2Si_2O_7$. How wholly unwarranted was the substitution by Benedicks of his formula for yttrialite is shown by the molecular ratio for $RO : R_2O_3 : SiO_2$, which he gives as 1 : 2 : 4 instead of 1 : 3·25 : 7·42 as calculated by me from Mackintosh's figures, wherein for a sound reason I have converted his UO_3

* Bull. Geol. Inst. Upsala, iv, 1, 1898. † This Journal, xxxviii, 477, 1889.

into UO_2, thus throwing it with the ThO_2, where it naturally belongs. The agreement is indeed "gar nicht gut."

Benedicks has made the grave mistake of counting Mackintosh's monoxide bases a second time, thus making a basic salt $R''R'''_4Si_4O_{15}$ instead of the normal one $R'''_4Si_4O_{14}$, to which Mackintosh's results closely conform.

Discussion of Benedicks' formula for Thalénite.

Moreover, in the light of the data furnished by Benedicks himself it cannot be admitted that the formula $H_2Y_4Si_4O_{15}$ for thalénite is established.

Water was determined by him according to Penfield's method,* but without any hint as to the particular modification employed. If, as seems probable, the water expelled from the mineral was caused to recondense in the cooler part of the ignition tube, the latter being then weighed and again after driving the condensed water out, two serious sources of error have to be considered: (1) The CO_2 present in the mineral, which would count in part as water unless a very careful correction was made, as provided for by Penfield. No mention is made by Benedicks of any such correction. (2) Nitrogen and helium are said to comprise 1·4 per cent of the mineral by weight. If so, these would introduce an error in the above water determination of contrary sign to that due to CO_2, and if the proportion of helium were large this error might be of very considerable magnitude.

In an appendix to his paper Benedicks gives an analysis of what he considers to be a very pure form of thalénite. He makes no comparison of this with his earlier analysis, nor does he deduce a molecular ratio, which I find to be 1 : 2·6 : 5·15, or 1 : 3·03 : 6·02 if small amounts of lime, magnesia, and soda are neglected, instead of 1 : 2 : 4 as required by his formula. There being no CO_2 in this purer material, the value for water (if determined as above surmised) may be supposed to be affected only by the error due to nitrogen and helium. It will be seen that the neglect to regard lime, magnesia, and soda in his second analysis affects the ratio very seriously. This neglect may be justified in figuring on his first analysis because of an approximate balancing by CO_2, but it would be by no means so in the other in spite of the very satisfactory ratio obtained and leading to the empirical formula $R''R'''_6Si_6O_{22}$, which is susceptible of a variety of interpretations. It may represent a basic salt of diorthosilicic acid $R''R'''_5(R'''O)'Si_2O_7)_3$ or of metasilicic acid $R''R'''_2(R'''O)'_4(SiO_3)_6$, or possibly even of other acids.

* This Journal, xlviii, 31, 1894.

Finally, if the values for nitrogen and helium are really anywhere near so great as given, an additional argument against the validity of his formula is furnished. For, in the light of Kohlschütter's recent researches* and my own less conclusive work of a much earlier date,† it is in the highest degree probable that nitrogen and helium are not occluded in uraninite and other minerals but are in chemical combination. Now, if this is so, in a mineral containing as much as 1·4 per cent of nitrogen by weight this must, quite irrespective of its form of combination, play so important a role in the molecule as to utterly invalidate any formula based on calculations from which it is omitted. If the above percentage is made up in large part of helium, its effect, because of its low atomic weight, must be vastly greater than that of nitrogen.

Until light is thrown on the nature of the combinations these two gases form in minerals, no very positive conclusions can be reached as to the formulas to be assigned to those minerals which contain them in more than traces.

Chemical investigation of Yttrialite.

At the earnest request of Mr. W. E. Hidden, the discoverer of yttrialite, I undertook to reanalyze the mineral in order if possible to settle definitely the question of its composition. This seemed especially desirable since a large quantity of very fine material was available.

The appearance and behavior of the mineral agreed in all respects except one with those of the original description.‡ It is there stated that the strongly ignited mineral is insoluble in acid. This is a mistake, for when powdered the solubility in hydrochloric acid is even then perfect, although not rapid.

Careful examination of thin sections under the microscope showed a condition that augured ill for decisive analytical results despite the apparently fine quality of the large specimens. Distinctly foreign mineral fragments were as good as absent except for insignificant coatings of a white alteration product, presumably a carbonate, but considerable shading was apparent in the slides, indicative of alteration or intimate contamination in the mass of the mineral itself. However, after treatment with hot dilute hydrochloric acid (whereby much yttrialite was dissolved) followed by dilute sodium carbonate, the clear glassy residue appeared to be improved in appearance and the specific gravity of two samples, each composed of small grains uniform in size for each sample, had risen from 4·596 and 4·590 to 4·654

* Ann. der Chem., cccxvii, 158, 1901.
† Bull. U. S. Geol. Surv., No. 78, pp. 76–78, 1891.
‡ This Journal, xxxviii, 477, 1889.

at 23½° C and 4·646 at 26° C. respectively. The two sizes were then mixed, giving one sample of about 4·65 sp. gr. at 25° C. That of the unpurified material analyzed by Mackintosh was 4·575.

Qualitative tests showed the absence of zirconium, glucinum, and aluminum and the presence of a little more than a trace of fluorine, of a very little carbon dioxide, besides some other gases which were set free by treatment with acids and by fusion with an alkali carbonate.

Silica was separated by two evaporations with hydrochloric acid; lead was then thrown out by hydrogen sulphide.

The earths when finally collected together free from all iron, manganese, uranium, titanium, phosphorus, calcium, and magnesium, were ignited and weighed. No filtrate from a precipitate of earth-oxalates was ever regarded as free from earths till after evaporating, igniting, and retesting. This is a needed precaution in all similar analyses.

The combined earths were dissolved in nitric acid and evaporated to dryness. A saturated solution of potassium sulphate was poured upon the dry mass, which wholly dissolved but almost at once began to deposit double sulphates. Solid potassium sulphate was then added in crystals. After twenty-four hours the precipitate was collected on a filter and washed with the precipitant solution. Twice was this precipitation repeated after first dissolving the double salts in acid, precipitating by potassium hydroxide, washing, redissolving in nitric acid, and evaporating. Then only was the extraction of the yttrium-erbium group practically complete. From the combined filtrates the soluble earths were thrown out, reconverted into nitrates, and again treated with potassium sulphate, whereby a little further insoluble matter was obtained. Yttrium-erbium oxides obtained from the oxalates gave a light-colored mixture of 265·6 Mol. W. (108·8 At. W.), which furnished a pink nitrate solution showing the erbium absorption bands strongly marked, with very faint indications of the strongest band of the didymium components.

The insoluble sulphates were converted into chlorides and thrice treated with potassium hydroxide and chlorine to precipitate thorium and cerium. From the filtrates the soluble earths were recovered and subjected to a repetition of this treatment. Their oxides after purification were light dirty brown when heated over the Bunsen flame, but grayish white when blasted. Their Mol. W. was 335·5 (At. W. 143·7); their nitrate solution was pink and gave the characteristic didymium component absorption bands altogether free from those of the erbium constituents.

Cerium and thorium were separated by a combination of the

ammonium oxalate and thiosulphate methods. The weighed thoria was pure white, the ceria of a pale salmon color.

The condition of the uranium was shown by its precipitability as tetrafluoride on dissolving the mineral in hydrofluoric acid. This reaction afforded a ready means of estimating with exactness the ferrous iron by permanganate after rapidly filtering off the fluorides precipitated in an atmosphere of carbon dioxide. Solution of the mineral in a sealed tube with dilute sulphuric acid allowed of finding the oxygen value of both UO_2 and FeO by permanganate. The result thus found for OU_2 agreed marvelously well with that calculated from the U_3O_8 found gravimetrically in a separate portion.

Analyses of Yttrialite.

	Hillebrand.		Mol. Ratios.	Mackintosh.		Mol. Ratios.
SiO_2	29·63		·4938	29·17		·4861
TiO_2	·05			—		
ThO_2	10·85		·0470	12·00		·0483
UO_2	1·64	(1		·79	(1	
Ce_2O_3	3·07			1·86		
La_2O_3, etc.	5·18	(2		2·94	(2	
Y_2O_3, etc.	43·45	(3		22·67	(3	
"				5·30	(4	
"			·1930	4·50	(5	·1864
"				14·03	(6	
Al_2O_3	—			·55		
Fe_2O_3	·76			—		
FeO	1·96			2·89		
MnO	·88			·77		·0655
PbO	·80			·85		
CaO	·67		·0608	·60		
MgO	·16					
H_2O+105 C.	·32					
H_2O-105 C.	·04			·79		
CO_2	·11					
P_2O_5	·12					
N, He, Fl, Alk	Diff. ·31					
	100·00			99·75		

1) Volumetrically. Gravimetrically 1·62%.
2) At. W. 143·8 (Mol. W. 335·6).
3) At. W. 108·8 (Mol. W. 265·6).

1) Given as ·83UO_3 by Mackintosh.
2) At. W. 162 (Mol. W. 372).
3) At. W. 110·3 (Mol. W. 268·6).
4) At. W. 110·53 (Mol. W. 269·06).
5) At. W. 114·9 (Mol. W. 277·8).
6) At. W. 120 (Mol. W. 288).

Nitrogen (?) and helium (?) were obtained quantitatively by fusing the mineral with sodium-potassium carbonate in a current of carbon dioxide and collecting the gases in a nitrometer over potassium hydroxide. The volume was between one and two cubic centimeters per gram of yttrialite. The gases were not further examined.

The analysis is given above, together with that of Mackintosh for comparison.

The ratios of Mackintosh's analysis as calculated above by me are certainly wrong in so far as they are affected by the value for iron, which he assumed to be wholly ferrous. If corrected in accordance with the statement of my analysis, or, what amounts to the same thing for the purpose of illustration and is simpler, if my ratio is altered to conform to his statement for RO and R_2O_3 bases it becomes ·0644 : ·1882, a very close agreement.

It is altogether probable that Mackintosh's separations of the earths were not so far reaching as mine, and this belief is borne out by the differences in the experimental molecular weights for the lanthanum and yttrium groups, mine being more in accordance with what might be expected and, moreover, agreeing almost exactly with those which were found by me for rowlandite in 1893, namely, 336·8 and 266·2 respectively.*

It is of course impossible to say what disposition should be made of the small amounts of firmly held water, phosphorus, carbon dioxide, fluorine, and alkalies. The ratios of my analysis are, therefore, to a slight extent incorrect, but probably not enough to influence any conclusions that may be drawn. One thing is apparent, that the preliminary purification by acid has had no pronounced effect on the composition of the mass acted on, otherwise Mackintosh's and my analyses should show far greater differences in the main constituents.

The crude empirical formulas deducible from the ratios of the two analyses are nearly

* The three minerals gadolinite, yttrialite, and rowlandite occur in Llano County in most intimate association, suggestive of close community of origin, a suggestion which is emphasized by the marvelous agreement for gadolinite and yttrialite, not only in the relative proportions of the trivalent earth metals but in their absolute amounts as well.

	Ce_2O_3	La_2O_3, etc.	Y_2O_3, etc.
Gadolinite (Genth)	2·65	5 22	44·35
" "	2·66	5·01	44·45
" (Eakins)	2·62	5·22	41·55
Yttrialite (H'b'd.)	3·07	5·18	43·45
Rowlandite (")	5·06	9·34	47·70

This concordant testimony of three analysts may be regarded as strong evidence of the correctness of the earth separations made by them in these cases. Nearly the same relation is shown by the trivalent earth-metals of rowlandite, as seen in the table above.

Hbd.	R''_{61}	R'''_{386}	R''''_{47}	$(Si_2O_7)_{247}$
Mack.	R''_{65}	R'''_{373}	R''''_{48}	$(Si_2O_7)_{243}$

there being a slight *deficiency* of oxygen atoms in each case for the radical Si_2O_7, which is increased by allowing for the CO_2 and P_2O_5.

In so far then as the character of the acid radical is concerned the results of Mackintosh's analysis are fully confirmed and there is absolutely no ground for accepting Benedicks' basic formula, which as I have already shown (p. 145) is based on a palpable error. But the ratios are not at all such as to lend themselves to ready resolution into isomorphous salts of the acid $H_6Si_2O_7$. By doing quite unwarranted violence to the analytical data the above formulas might be reduced to

$$R'' \quad R'''_6 \quad R'''' \quad (Si_2O_7)_4$$

which can be readily represented structurally as a single complex molecule or as a mixture of molecules like $3R'''_2Si_2O_7 + R''R''''Si_2O_7$. In neither case, however, is the type of the rowlandite molecule approached, which requires an altogether different ratio of monoxide, dioxide, and trioxide bases, nor, if the second be accepted, is it at all clear that the two molecules would be mineralogically equivalent, that is, isomorphous.

An alternative hypothesis is to regard the mineral as a mixture containing the anhydrous thorite molecule. Proceeding on this assumption and deducting all thorium and uranium and the proper amounts of silicon and oxygen, the crude empirical formulas become

Mack.	R''_{65}	R'''_{373}	$Si_{438}O_{1501}$	
Hbd.	R''_{61}	R'''_{386}	$Si_{447}O_{1533}$	

which may be interpreted as basic salts of metasilicic acid:

	R''_{65}	R'''_{185}	$(R'''O)'_{187}$	$(SiO_3)_{438}$
	R''_{61}	R'''_{194}	$(R'''O)'_{192}$	$(SiO_3)_{447}$
or	R''	R'''_3	$(R'''O)'_3$	$(SiO_3)_7$

this last being easily susceptible of symmetrical representation in graphic form.

On the whole I prefer to leave the constitution of yttrialite unsettled until further evidence can be gathered, either from analyses of allied minerals or from yttrialite itself of more certain purity than any that has yet been discovered.

It must not be forgotten that the gases other than CO_2 contained in the mineral may be the cause of the inability to arrive at satisfactory conclusions in the case of this and all other minerals which contain them, as I have already pointed out on p. 147.

My excuse for such a lengthy publication on a matter still unsettled is the desire to prevent general acquiescence in the grouping under one type of minerals which can by no means be regarded as proven to belong to that type, and to which yttrialite certainly does not belong.

Summary.

The empirical formula of Hidden and Mackintosh for yttrialite is confirmed, and it is shown that the basic formula of Benedicks rests on error and has no standing.

The formula of Hidden and Mackintosh is not, however, susceptible of representation as a simple salt of the acid $H_6Si_2O_7$. On the purely hypothetical assumption of admixture of anhydrous thorite, the remaining constituents afford ratios conforming quite closely to those of a basic metasilicate $R''R'''_2(R'''O)'_2(SiO_3)_7$.

It is shown for two reasons fully discussed that the formula proposed by Benedicks for thalénite is to be regarded as doubtful.

Laboratory U. S. Geol. Survey,
Washington, D. C., Nov. 19th, 1901.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *Apparatus for Determining the Density of Liquids.*—A very simple means for taking the specific gravity of liquids has been devised by F. Girardet. It consists of two perpendicular glass tubes, resembling barometer-tubes, which are open at the bottom, and are connected at the top so that suction can be applied to both tubes at once by means of a rubber tube. Each tube has behind it a paper millimeter scale extending from an arbitrary zero point a few centimeters above its bottom to 500^{mm} or more, near the top. To take the specific gravity of a liquid, the latter is placed in a small, cylindrical, glass vessel so that one of the upright tubes dips into it, while distilled water is placed at the mouth of the other tube and in a dish of the same size. Suction is now applied until the liquid to be tested remains, when a screw-clamp on the rubber tube is closed, at a convenient point high up in the tube, say 500^{mm}, and the height of the water is also read. Then air is admitted until the columns have fallen to points near the bottoms of the scales, for example, until the liquid to be tested is at zero, when the positions of the two columns are again recorded. It is evident that the columns thus measured are inversely as the specific gravities of the liquids; hence, since one of them is water, it is only necessary to divide the fall of the water column by that of the other liquid in order to obtain the specific gravity of the latter. The effect of capillarity is eliminated by the two readings if the tubes are of uniform caliber. In the apparatus described the tubes were of about 8^{mm} exterior diameter, so that the quantity of liquid needed was very small. Determinations were made with various liquids, and results were obtained which agreed closely with those obtained by a Mohr's balance. Slight errors were encountered when volatile liquids were used, but satisfactory results were obtained with ethyl alcohol and with ammonia of ·985 specific gravity. The apparatus is easily constructed at slight expense; it is much more accurate than ordinary specific gravity spindles, and it may be used to replace a series of these, as it is applicable to liquids which are heavier or lighter than water. Where readings are made to $\frac{1}{2}^{mm}$, with columns of about 400^{mm}, the probable error is calculated to be $\frac{1}{2400}$ of the absolute value. The time required for the determination is only about one minute.—*Bulletin*, xxv, 936. H. L. W.

2. *The supposed Existence of an Oxide of Hydrogen higher than the Dioxide.*—The possible existence of an oxide of hydrogen higher than H_2O_2 was suggested by Bach a year or two ago, on the ground that when hydrogen peroxide is acidified with sulphuric acid the amount of oxygen evolved by potassium permanganate is greater that the amount calculated from the permanganate used. Ramsay has now confirmed the fact just stated, but

he finds that the discrepancy is due to the formation of some persulphuric acid when the sulphuric acid is added to the hydrogen peroxide. He finds that when acetic acid is used for acidifying, the evolved oxygen corresponds with the theory. It is evident that these results have an important bearing upon the customary method of titrating hydrogen peroxide solutions, and that sulphuric acid should not be used in this operation.—*Jour. Chem. Soc.*, lxxix, 1324. H. L. W.

3. *The Atomic Weight of Calcium.*—Hinrichsen has made four determinations of this atomic weight by igniting Iceland-spar and finding the loss in weight due to the expulsion of carbon dioxide. The material was carefully analyzed, and found to contain no impurity except ferrous carbonate corresponding to ·032 per cent of Fe_2O_3. This impurity was taken into account in making the calculations. The quantity used for each experiment was about 30^g of the mineral. The ignitions were made in a large bottle-shaped platinum crucible with a specially constructed electrical furnace as the source of heat. During the ignitions dry air was aspirated through the crucible in order to remove the carbon dioxide as fast as it was set free. The results, 40·144, 40·141, 40·142 and 40·141, where oxygen is taken as 16 and carbon as 12, show a remarkably close agreement and indicate that the usually accepted atomic weight, 40·0, is somewhat too low.—*Zeitschr. physikal. Chem.*, xxxix, 311. H. L. W.

4. *Silver Subhalides.*—These compounds, which are supposed to be represented by the formulas Ag_2Cl, Ag_2Br and Ag_2I, are of considerable interest because they are probably formed by the action of light on the ordinary halides in photographic processes. Many attempts have been made to prepare these substances in a pure condition, and it has been supposed that Vogel had accomplished this by the reaction of the cuprous halides upon silver nitrate in solution. Emszt has now shown, however, that the products made according to Vogel are merely mixtures of the ordinary halides with metallic silver. He has shown, contrary to Vogel's belief, that metallic mercury dissolves silver from the products, and, moreover, he has found that it is possible to change the compositions of the products by simple elutriation.—*Zeitschr. anorg. Chem.*, xxviii, 346. H. L. W.

5. *The Atomic Weight of Tellurium.*—In the last number of this Journal (page 60 of this volume) attention was called to an investigation by Pellini on the atomic weight of tellurium, in which results were obtained showing a value of 127·6, a number higher than that of iodine, and closely agreeing with the results of a number of other investigators. Köthner has now made an elaborate research on the same subject, and by the ignition of the basic nitrate, a method which orignated with the Americans Norris, Fay and Edgerly, he has obtained an average result which is precisely the same as that of Pellini. It seems probable that this atomic weight is now established within very narrow limits.—*Liebig's Annalen*, ccexix, 1. H. L. W.

6. *Compounds of Hydrogen Peroxide with Salts.*—S. TANATAR has prepared a curious molecular compound of hydrogen peroxide and potassium fluoride with the composition corresponding to the formula $KF{\cdot}H_2O_2$. It forms large monoclinic crystals and is prepared by treating a very concentrated solution of the two substances—hydrogen peroxide being in excess—with alcohol, then separating the lower of two layers of liquid which form, treating again with alcohol, and evaporating in a desiccator. In a somewhat similar manner the compound $Na_2SO_4{\cdot}9H_2O{\cdot}H_2O_2$ was prepared. This is evidently Glauber's salt in which one molecule of water of crystallization is replaced by hydrogen peroxide. From an alkaline solution of sodium nitrate the remarkable compound $NaNO_3{\cdot}Na_2O_2{\cdot}8H_2O$ was produced.—*Zeitschr. anorgan. Chem.*, xxviii, 255. H. L. W.

7. *Drift of the Ether.*—Dr. W. M. HICKS communicates a long mathematical paper on Michelson and Morley's experiment in regard to the motion of the ether. He points out that reflection produces a change in the wave-length of the reflected light. Further, when the source of light moves with the apparatus, the light incident at any instant on a plate does not come from the position occupied by the source at that instant, but from a point which it occupied at some interval before: consequently the angle of incidence alters by a small quantity of the first order as the direction of drift of the apparatus changes. The principal result of the correction is that in the experiment of Michelson and Morley the effect to be expected is the reverse of that hitherto supposed.—*Phil. Mag.*, Jan. 1902, pp. 9–42. J. T.

8. *The Clearing of troubled Solutions.*—G. QUINCKE reviews the work of previous writers on the causes of the suspension of fine particles of various substances in water. Prof. J. J. Thomson and Mr. Hardy sought the ground of this long suspension in the electromotive force at the boundary of the suspended particles and the surrounding liquid, which opposed the movement of the solid particles. Since according to Dorn electric work would be afforded by a displacement of the particles, the working would be the same as if the viscosity of the fluid should be increased. Quincke's observations do not support this hypothesis. He finds the main cause of the suspension in the hydrodynamic forces, which the swimming or slowly falling particles excite in the surrounding fluid. Quincke does not agree with Barus, Hardy and Spring, that a phenomenon of electrolysis enters. He sums up his observations under ten heads, which relate to the various phenomena observed in solutions containing suspended particles. —*Ann. der Physik*, No. 1, 1902, pp. 57–96. J. T.

9. *Displacement Currents.*—In a previous paper, M. R. BLONDLOT showed that if a mass of air is moved in a magnetic field normally to the lines of force, no electric displacement results in this mass of air. From this it follows that a mass of air which is the seat of an electric displacement should undergo no action in a magnetic field. If the principle of action and reaction is

applied to this proposition, it leads to the conclusion that a current of displacement in the air exerts no magnetic action, and consequently that the charging current of a condenser is an open current from the magnetic point of view. This is in direct opposition to one of the fundamental principles of Maxwell's theory, and choice has to be made between renouncing this theory or the principle of action and reaction.—*Comptes Rendus*, Nov. 25, 1900; *Nature*, Dec. 5, 1901. J. T.

10. *Frequency-determination of slow Electrical Vibrations.*—K. E. F. SCHMIDT places a telephone opposite the end of a resonance tube and pushes a metallic disc to and fro in the tube until the sound of the telephone is reinforced. In this way he obtains the wave-length of the note of the telephone. He gives a table of readings to show the accuracy of the method. The determinations of the position of the minima varied from each other hardly more than one millimeter, when the length of the wave was $9{\cdot}356^{cm}$. He also used Kundt's dust figures, and obtained remarkably sharp and beautiful figures. Another method consisted in using a single straight filament in an incandescent lamp, and setting a photographic plate suspended from a pendulum in motion. The plate shows maxima and minima corresponding to the frequency of the current feeding the lamp.—*Ann. der Physik*, No. 1, 1902, pp. 225–231. J. T.

11. *The Bearing of the upward and downward Movement of Air on Atmospheric Electricity.*—F. LINKE dwells upon the fact that if at any place an electrostatic potential A exists and a conducting body of capacity C is in equilibrium, a quantity of electricity $E_A = C.A$ results. If we now bring this body to a place of potential B, then we should have a quantity of electricity $E_B = C.B$ neglecting disturbing influence of the field: the difference $E = C(A-B)$ must become free, if no change takes place in capacity. In an electrostatic field, like that of the earth, any change of a body in the direction of the force lines must result in free electricity. The author finds in the rise and fall of charged clouds a cause of lightning potential, which to his mind is far more plausible than theories of the friction of water on ice and condensation on ions.—*Ann. der Physik*, No. 1, 1902, pp. 231–235. J. T.

12. *Notes on Quantitative Spectra of Beryllium;* by W. N. HARTLEY.*—In a quantitative examination made in 1885 of all the known methods of separating beryllium from aluminum and from iron, the various precipitates obtained were dissolved and diluted to a known volume corresponding with the amount of bases in solution.

The solutions were spectrographically examined, and the photographs compared with others taken from solutions containing accurately weighed quantities of pure beryllia. The coil used was capable of giving a 5-inch spark in air. In place of a Leyden jar a pane of glass coated on each side with a square foot of tin-

* Read before the Royal Society, Dec. 5, 1901; from an advanced proof received from the author.

foil was used. The electrodes* were Ceylon graphite as in other experiments, the sole impurity in which was a trace of magnesium.

The following tabulated statement gives the wave-lengths of the lines, together with a description of the spectra photographed from solutions of different strengths :—

Strength of Solutions or Degrees of Dilution shown by per cent of Beryllium.

Beryllium wave-lengths (Rowland's scale).	1 per cent.	0·1 p. c.	0·01 p. c.	0·001 p. c.	0·0001 p. c.	0·00001 per cent.	0·000001 per cent.
3322·3	Continuous line	Half of line much weakened	Very short line	Faint indication	Extinct	Extinct	Extinct
3130·3	"	Continuous line	Half of line weakened	Half of line weakened	Line one-half shorter	Half line still strong	Nearly one-half, still strong
2649·8	"	Half of line weakened	Very short line	Very short line	Dot merely	Dot	Dot
2493·6	"	"	"	"	Very faint dot	Dot, scarcely visible	Dot, scarcely visible
2478·1	"	Continuous line	Short line	Very fine short line	Very short line	Fine short line	Fine short line

The actual length of the line 2478·1, as rendered by solutions of 0·00001 per cent and 0·000001 per cent strength, is, in the former, 0·07, and, in the latter, 0·05 of an inch. The normal length of the line at this part of the spectrum is 0·22 of an inch. The quantity of substance yielding this spectrum is equivalent to one-millionth of a milligram of beryllium. As I have pointed out in the case of magnesium,† so also is it with beryllium, that the sensitiveness of the spectrum reaction may be increased ten thousand-fold by using a larger coil and more powerful condenser, but leaving the striking distance between the electrodes unaltered. The coefficient of complete extinction was therefore practically not attainable for all the lines, or, in other words, the sensitiveness of the reaction is almost without limit.

It will also be seen from my description of the spectra, which have been quite recently re-examined, that the coefficient of extinction of the two lines λ 3130·3 and 2478·1 had not been reached by the dilution specified.

A number of thin sections of the Dublin granite containing microscopic crystals of hexagonal form were examined some years ago. The crystals were supposed to be apatite, but a very carefully executed analysis disclosed the fact that the proportion of phosphoric acid contained in 20 grams of the rocks was almost

* Phil. Trans., 1884, Part I, p. 49.
† Phil. Trans., 1884, Part II, p. 325.

infinitesimal, and that on warming thin sections, in which the hexagonal crystals were visible, with nitric acid and ammonium molybdate, no deposit of yellow ammonium phospho-molybdate could be detected by the microscope. A spectrographic analysis showed that these crystals were really beryls, and similar crystals a millimeter in length were picked out of the granite. They were found to contain between 10 and 11 per cent of beryllia. Since then beryllia has been separated from the alumina of feldspar obtained from the granite in Glen Cullen in proximity to a vein of coarse granite in which beryls were found by Dr. John Joly.

From numerous experiments on the analytical processes employed in the separation of beryllia from alumina, it was found that it remained combined with the sesquioxide bases in so persistent a manner as to lead to the belief that ordinary alumina might be found more often than not to contain traces of beryllia, particularly as there is no easily applied chemical test for detecting its presence in small quantities, nor a simple means of separating it. It has, however, been found that such is not the case, though gallium has been ascertained to be present in almost all minerals which contain aluminum. As they belong to the same group, the two elements aluminum and gallium may be expected to form isomorphous mixtures, which would account for their being so constantly associated in nature; but the position of beryllium in the periodic sytem of classification shows that a similar behavior with that element is scarcely probable.

13. *Vector Analysis:* a Text-book for the use of Students of Mathematics and Physics, founded upon the lectures of J. Willard Gibbs; by Edwin Bidwell Wilson. Yale Bicentennial Publications. New York and London, 1901. (Charles Scribner's Sons.) Pp. xiii–436.—As indicated by its title, this book embodies the substance of Professor Gibbs' lectures on Vector Analysis, with such illustrations and extensions as seemed necessary to the editor, Dr. Wilson. Since the publication, over twenty years ago, of Professor Gibbs' small pamphlet on the subject, there has been a growing need for some more elaborate text-book which should contain such theorems, examples and problems as would enable one who mastered it to apply its methods to the fields of mathematical physics and pure mathematics. University students have felt the need of such a book also, for the number of writers who are making use of the methods and symbols of Vector Analysis is increasing each year. Mention need be made of only a few, such as Heaviside, Föppl and Walker.

This is not the place nor the occasion to discuss the general question as to the usefulness of Vector Analysis: it may in fact be said to be decided. Whether new theorems can be deduced by means of it may be doubted; but no one can deny that new points of view may be obtained and that more elegant solutions may be given.

In the work under review, there is a general discussion of Vector Analysis, together with its most important applications.

As Dr. Wilson explains in his preface, the book is divided roughly into three distinct parts. In the first are treated the addition and products of vectors; in the second, the application of the differential and integral calculus; in the third, the theory of the linear vector function and a few special applications. There are seven chapters, each of which is concluded by an excellent summary and a few selected exercises.

The scope of the work may best be indicated by a résumé of the table of contents. Chapter I discusses scalars and vectors, addition and subtraction, the three unit vectors i, j, k, centers of gravity, representation of areas; chapter II, scalar and vector multiplication, reciprocal systems, kinematics and dynamics of a rigid body; chapter III, kinematics of a particle, the vector and scalar differentiating operator, divergence, curl, and combinations of these operators; chapter IV, the theorems of Gauss, Stokes and Green, and the integrating operators, "potential," "newtonian," "laplacian" and "maxwellian"; chapter V, the theory of linear vector functions and the application of various theorems in regard to dyadics; chapter VI, the description and discussion of rotations and strains by dyadics; chapter VII, applications of vector analysis to quadric surfaces and the theory of light.

From the first page to the last, the logical development is clear and forcible. Special attention is paid at every point to render the book efficient for use in a class; and anyone having an opportunity to instruct a class in Vector Analysis would certainly be most grateful to Dr. Wilson.

The book is to be recommended to every student of physics and mathematics, and the thanks of every reader are due the publisher for the excellence of the type and paper. No important typographical errors have been noted; but the absence of an index is unpardonable. J. S. A.

II. Geology and Natural History.

1. *Catalogue of the Types and figured Specimens in the Palæontological collection of the Geological Department, American Museum of Natural History;* by R. P. Whitfield, assisted by E. O. Hovey (vol. xi, Bull. Am. Mus. Nat. Hist.); pp. 1–500. 1898–1901.—The completion of this catalogue of one of the most important series of Paleozoic fossils in the United States, representing as it does a large proportion of the types upon which American Paleozoic paleontology is founded, calls for special notice. From the preface of the completed work written by the able author, the following quotation is made, viz:

"This Hall collection may well be considered the standard reference collection for all workers in North American Palæozoic palæontology. Most of the 'figured specimens' in the series are those which were identified, redescribed, illustrated and published by Prof. Hall in the early volumes of the Palæontology of

New York, and therefore have almost the dignity and value of types.

Of the specimens described and illustrated in the quarto volumes of the Palæontology of New York, the Museum possesses two-thirds of those in volume i, covering the Cambrian and Lower Silurian systems; nearly eight-tenths of those in volume ii, extending from the Medina to the Onondaga stages, inclusive; three-fourths of those in volume iii, which treats of the Lower Helderberg and Oriskany Groups; more than one-third of those in volume iv, which describes the Brachiopoda of the Devonian system from the Upper Helderberg to the Chemung; about thirty per cent of the specimens illustrated in volume v, part i, which is devoted to the Lamellibranchiata of the Upper Helderberg (or Corniferous), Hamilton and Chemung Groups; and a nearly equal proportion of the Cephalopoda and Gastropoda illustrated in volume v, part ii. The collection, however, contains only about 74 of the specimens of Bryozoa given in volume vi, and about 70 of the Crustacea illustrated in volume vii of the Palæontology of New York. Much of the material for volume viii, on the Brachiopoda, was prepared for publication prior to 1876, hence a large proportion of the specimens used for illustrations are to be found in the American Museum, especially of those used for the plates bearing the name of R. P. Whitfield.

There are in this Department of the Museum 8,345 type and figured specimens, representing 2,721 species and 190 varieties."

2. *The Laccoliths of the Black Hills;* by T. A. Jaggar, Jr. with chapter on *Experiments illustrating Intrusion and Erosion;* by Ernest Howe. 21st Ann. Rep. U. S. Geological Survey, Part III, pp. 163–303. Washington, 1901.—This paper presents the results of a careful and detailed study and mapping of the igneous intrusions in the northern Black Hills in South Dakota and Wyoming. A large number of laccolithic bodies are described, aided by maps and cross sections, and their geologic relations and mode of occurrence deduced. The subject is presented chiefly from the structural and dynamical side. From the facts thus presented the author derives a number of interesting and important conclusions regarding the formation of igneous masses of laccolithic character in sedimentary strata. He points out especially the importance of orogenic disturbances and deformations in promoting their origin. He also gives interesting studies showing the results of the gradual dissection by erosion of domed uplifts produced in this way. The whole constitutes a notable contribution to the literature on igneous intrusions.

In the chapter by Dr. Howe are given the results of experiments in which molten wax was forced upward from below into a mass of previously prepared sediments. The uplifts thus made simulate in all important particulars those seen in laccoliths, as shown in the photographs of the dissections. The erosion produced by a rain of fine spray shows results much like those seen in nature. The chapter as a whole is an interesting addition to

the experimental mechanics of geology, and the facts tend largely to confirm previous views regarding the origin of laccoliths, especially in respect to the importance of viscosity of the magma as a factor in their production. L. V. P.

3. *Analcite in Igneous Rocks.*—In a recent paper on a monchiquite from Mount Girnar Junagarh, Kathiawar (Quar. Jour. Geol. Soc., vol. lvii, p. 38, 1901), Dr. J. W. Evans shows that the isotropic base is composed of analcite. This is proved by its chemical composition, specific gravity, optical properties and reaction with acids. The author remarks that it might have all these characters and still be a structureless glass. This is true, but only as a possibility so remote that it may be said to have little practical importance. When we consider that a glass has no definite composition, and that to satisfy the properties demanded by analcite there must be five numerical factors (including sp. gr.) which must be arranged in definite ratios, the great improbability of such an agreement becomes at once evident. Adding to this agreement the capability of gelatinization, possessed by basic glasses, but so far as known not by silico-aluminous ones, and still more the improbability of glass forming under such physical conditions as have influenced the crystallization of these dikes and the probability becomes still more remote.

But Dr. Evans has called attention to still another means of discrimination, the cubic cleavage of analcite. This is quite marked in the rock from India and is clearly shown in the microphotograph of the thin section. The suggestion of the use of this character, overlooked by previous investigators, is a valuable one where it can be applied. I have studied a section from the original type of Rosenbusch, from the Santa Cruz Railway near Rio Janeiro, and under high powers the cubic cleavage of the analcite is very clear and evident, thus confirming its crystalline nature. A study of similar rocks from other localities shows in some cases this cleavage in the isotropic base, in other cases it is apparently wanting. Where the areas of the base are comparatively large it usually appears, where the amount of base is very small and the interspaces minute it cannot be detected. Often, however, in these cases the base by a more reflected light is seen to be of fine granular or even fibrous character, thus indicating crystallization of some sort. L. V. P.

4. *Researches on Cellulose, 1895–1900;* by C. F. Cross and E. J. Bevan. London, 1901 (Longmans, Green & Co.). — A previous volume by these authors, in 1895, gave a comprehensive view of the subject of cellulose, up to that date. It contained, also, a full account of the interesting discovery made by them, that cellulose treated with caustic alkali dissolves in carbon disulphide, and can be recovered from this solution in a more or less pure state. The authors also described to some extent a technical product obtained by them, on carrying out this process with certain modifications of detail. This product, now known

in the arts as *viscose*, has commanded a good deal of attention on account of its applications to certain phases of textile industry, notably the dressing of cloth and the manufacture of an imitation of silk. The present volume is a convenient appendix to the former one, and brings together not only the rejoinders which the authors have made to some criticisms of their earlier work, but also some of the more important contributions to the subject of paper-pulp and the deterioration of paper. Chemists and botanists will be interested especially in the pages devoted to the constitution of cellulose or, rather, of the celluloses. The industrial applications of cellulose, although briefly treated, are presented in a manner calculated to stimulate further research.

G. L. G.

5. *The Memorial Greenhouses at the Harvard Botanic Garden* have an attached laboratory for certain lines of study in vegetable physiology. The buildings were erected specially with the design of giving ample accommodation for four or five advanced students, and an additional greenhouse, close by, is devoted to the use of a large class of elementary students of plant physiology. In the memorial building, the present equipment affords facilities for carrying on investigations in regard to the relations of plants to electricity. Use is made of currents supplied by the city electric company, not only for constant lighting, but also for experiments in connection with soil. Through suitable reduction of the voltage, provision is made for many sorts of apparatus required in the study of the effects of different currents upon plants. A set of speed-reducers connected with the motor gives wheels of all desired rates for clinostat observations of movements in all planes.

At present, researches are in progress by Mr. Plowman in regard to the behavior of plants in the magnetic field, and also when under the influence of weak currents of electricity. Mr. Jenkins is now working on the condition of roots in soil through which are passing currents strong enough to cause electrolytic action on gas- and water-pipes; Mr. Stickney is continuing studies in regard to the effects of certain poisons on plants, and Mr. Poole has in hand experiments of a novel character relative to the activities of plants in a saturated atmosphere. Mr. Miller is now closing his series of experiments in regard to the effects of a top layer of very fine soil upon the soil beneath. It has been claimed that such a layer of fine soil conserves the water in the soil under it, to such an extent as to warrant the employment of pulverizers in arid or semi-arid districts. The loss of moisture is unquestionably checked by this so-called "blanket" of dust, but Mr. Miller shows that the cover of dust must be practically pulverulent throughout in order to make it effective. The "caking" of the dust-cover, even if very slight, after a few drops of water have fallen on it, reduces greatly the efficiency of the protection.

G. L. G.

Obituary.

Clarence King, the distinguished geologist, explorer and author, died at Phoenix, Arizona on December 24, in the sixtieth year of his age. A notice is deferred till the following number.

The following tribute to Mr. King was unanimously adopted at a meeting of the members of the U. S. Geological Survey held at Washington on December 28th.

"It is with profound sorrow that we learn of the death of Clarence King, the first Director and, in a sense, the founder of the Geological Survey. In him we have lost not only a great scientific leader but a genial and accomplished gentleman whose personal qualities endeared him to all who knew him, and whose many acts of loving kindness have left a wide circle of friends in all walks of life to mourn his untimely death.

As organizer and, during ten years, Chief of the United States Geological Exploration of the Fortieth Parallel, he set higher standards for geological work in the United States and laid the foundations of a systematic survey of the country. He gave practical recognition to the fact that a good topographical map is the essential basis for accurate geological work.

As first Director of the present Geological Survey, he laid down the broad general lines upon which its work should be conducted and which, as followed by his able successors, have led to its present development. He established the principle that a Geological Survey of the United States should be distinguished among similar organizations by the prominence given to the direct application of scientific results to the development of its mineral wealth.

In that essential quality of an investigator—scientific imagination—no one surpassed King, and his colleagues have all profited by his suggestiveness. He was never content with the study of science as he found it, but always sought to raise the standard of geology as well as to apply known principles to the survey of the country.

King first introduced microscopical petrography into American geology and, as early as his Fortieth Parallel work, he foreshadowed the application of exact physics to questions of geological dynamics. Early in the history of the present Survey he established a physical laboratory. One result of this step was a paper on the Age of the Earth, which takes very high rank among modern scientific memoirs. Although in his last years circumstances rendered it necessary for him to devote most of his time to other occupations, he had by no means abandoned plans for geological investigation on a scale worthy of his reputation.

In Clarence King geological science in America will miss a pioneer and a leader; the Geological Survey loses its broad-minded founder and adviser, and its older members a beloved friend."

ALPHEUS HYATT, the eminent zoologist, died at Cambridge, Mass., January 15, 1902, in the sixty-fourth year of his age.

Outside of his many valuable publications in pure zoology, Professor Hyatt's chief reputation will rest mainly on his researches in the field of organic evolution. No other American has contributed so much toward the discovery of the laws of development and growth, and to an exposition of exact methods of research in evolutionary problems. The principles he enunciated constitute the foundation of a young and vigorous school of evolution, which is already making itself felt in the scientific world.

Alpheus Hyatt was born at Washington, D. C., April 15, 1838. He completed the Freshman year at Yale with the late O. C. Marsh, in the class of 1860; then, after traveling a year in Europe, he entered the Lawrence Scientific School at Harvard, and was graduated in 1862. He served during the civil war, attaining the rank of Captain. Later, he renewed his studies with Louis Agassiz, and has since been intimately identified with all the scientific interests centering about Boston. His official connections were with the Essex Institute, the Peabody Academy of Science, the laboratory of natural history at Annisquam, the Massachusetts Institute of Technology, Boston University, Teachers' School of Science, the Museum of Comparative Zoology, the United States Geological Survey, and the Boston Society of Natural History, of which he was the curator since 1881. In 1869, he was elected a fellow of the American Academy of Arts and Sciences, and in 1875 a member of the National Academy of Sciences. His name also appears in the roll of fellows and members of many other societies at home and abroad.

Among his principal publications should be mentioned: Observations on Polyzoa (1866); Fossil Cephalopods of the Museum of Comparative Zoology (1872); Revision of North American Poriferæ (1874–77); Genesis of Tertiary Species of Planorbis at Steinheim (1880); Genera of Fossil Cephalopoda (1883); Larval Theory of the Origin of Cellular Tissue (1884); Genesis of the Arietidæ (1889); Phylogeny of an Acquired Characteristic (1895); Guides for Science Teaching; and numerous essays on the stages of growth and decline in animals, and on various laws and problems of evolution. C. E. B.

THOMAS MEEHAN, the well known botanist and nurseryman, died on November 19 in his seventy-sixth year. An Englishman by birth, he came to Philadelphia in 1848, and was soon successfully established in the nursery business. He published many horticultural and botanical papers and also the two volumes entitled "Handbook of Ornamental Trees" and "The Native Flowers and Ferns of the United States" (1878–79).

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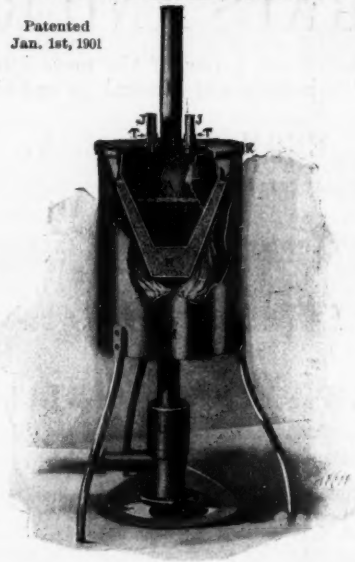

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